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HIGHWAY RESEARCH RECORD

Number	Planning Transportation Systems
399	
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Number | Planning Transportation Systems

399

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FOREWORD

This RECORD contains a series of papers relating to the broad area of transportation systems planning.

Passonneau discusses the problem of full compensation for acquisition of land for transportation improvements. The report reviews briefly several case studies that attempted to assess the potential impacts of a transportation corridor and their relation to the essential goal of equity. Although the cases do not address the basic question of whether to build or not to build, they suggest that full compensation will increase costs in high-density areas with the result that the transportation corridor will either be located farther away from high-density areas or be too costly to build.

Colony reports on the results of interviews taken at 228 households displaced by highway right-of-way acquisition. The results of the interviews indicated that unfavorable attitudes toward relocation dissipated during time and were inversely proportional to age and length of residence in the area and directly proportional to income and educational attainment. After relocation, relocatees had substantially higher monthly housing expenses, more than half those who had been tenants became homeowners, and one-third of the relocatees made longer trips to work. Relocation had the heaviest impact on the poor and the elderly.

Hall and Breuer propose a method for evaluating impacts of new freeways on desired land development patterns and on increasing employment and other socioeconomic activities. Benefits are defined in dollar equivalents, and an effectiveness-cost ratio is proposed for establishing corridor priorities.

Whitlock and Schoon discuss planning criteria for off-street service areas and examine the characteristics of existing truck-freight service areas in New York, Connecticut, Pennsylvania, and Texas. Relations between design and operational aspects are considered. A mathematical estimate of arrival rates is used to support the application of this technique for predicting use of an off-street truck-service area.

One of the continuing problems in regional planning is allocating limited funds to obtain the greatest benefit to the community. Koppelman and Shelkowitz advocate allocation of capital funds for construction of highways under the Tri-State region's 01 1985 interim plan for expressways. The paper suggests the portion of freeway investment funds that should be allocated to each subregional area, and measures benefits in terms of accidents, travel time, and vehicle-miles of travel.

Cockfield discusses a second-generation logic sequence for heuristically allocating urban structural space as a function of the population's daily or weekly physical activity patterns. The formulated design concept involves the aggregation of a system of activities as represented by their required space-time contents into subsets subject to certain land use and transport constraints.

Reitz discusses a telecount system, a research tool that improves data flexibility, estimates reporting time lag, and permits remote monitoring capabilities. Details of the system's operation through the first 6 months of service are included.

Canty and Golob present a general procedure for determining the potential national market and total socioeconomic and environmental impacts for an urban transportation system concept that can be considered for implementation in a number of urban areas.

Nez describes a new composite mapping system for land use modeling in states and regions. The system is specially designed for locating efficiency gradients or optimal zones for selected industries, major public facilities, and the like. The new process can readily handle a great variety of geographic data, local economic data, and transportation and social service phenomena. It can accept inputs of any form—tabulations, printed maps, or sketch maps. Its outputs are cartographic and statistical. It permits any combination of spatial data to be overlaid, with various weights, and readily composed into simulated patterns called composite maps.

FULL COMPENSATION IN URBAN ROADWAY CONSTRUCTION: A NECESSARY AND PRACTICAL OBJECTIVE

Joseph R. Passonneau, Daniel, Mann, Johnson, and Mendenhall,
Washington, D. C.

For there to be full compensation to all individuals and groups, all costs and benefits must be disaggregated and distributed accurately by geographical location, by social class, and over time. Full compensation for those displaced is possible, or very nearly possible, because of recent changes in legislation, in particular, the Relocation Assistance Act of 1970 and the Highway Act of 1970. But full compensation for people and institutions not displaced but disrupted cannot now be funded by federal or state highway building programs. Voids in existing knowledge of impact should be filled by (a) research in specific problems that might be called "consequential" research, (b) research in how communities (urban regional subareas) function and in what the effect of change is on members of communities, (c) research in regional function and regional change, in particular, in differential effects of differential accessibility, and (d) accurate records keeping on the impact of highway construction. Helpful legislation includes (a) creation of an impact zone within which "negotiated takings" are permissible; (b) payment of "consequential damages" for specified takings particularly in the impact zone; (c) investment of modest costs in the healing of the roadway-community edges; (d) requirement that scarce resources be replaced in kind; (e) provision of community planning money as part of the highway location and design process; and (f) distribution of the major share of Highway Trust Fund moneys directly to the states and directly to the major Standard Metropolitan Areas that generate them, with wide discretionary powers in the allocation of those funds, particularly the local matching shares.

•THAT expropriation practices do not provide full payment for "taking" is generally recognized. According to Allard (1),

...verdicts (by juries) are usually higher than the value of the taking as estimated on the basis of fair market value.... If the verdicts which have been rendered by juries in land-condemnation cases are an accurate measure, then another method to properly measure just compensation, aside from the fair market value concept, must be found.

In an excellent, pragmatic description of this problem sponsored by the Highway Research Board, Vance (2) cites *Monongahela Naval Company v. United States*, "Just compensation, it will be noticed, is for the property, and not to the owner." He goes on to list 9 specific losses to displaced persons (2):

The "payment for property taken" rule, as set forth in *Monongahela*, has been interpreted to deny payment for incidental losses or expenses incurred by property owners or tenants as a re-

sult of the taking of real property. Thus in the absence of a statute expressly so providing and authorizing, the courts have consistently denied recovery for, inter alia, the following losses and expenses:

1. The cost of moving personal property and the cost of disconnecting, dismantling, and re-installing structures, machinery, and equipment.
2. Transportation costs and other expenses incurred in moving a displaced family to replacement housing and the expenses incurred in searching for replacement housing or other types of property.
3. Expenses incidental to the transfer of title to real property required by the Government, such as recording fees, clerk fees, transfer taxes, etc.; penalty costs for prepayment of a mortgage and real property taxes paid to a taxing entity which are allocable to a period subsequent to the transfer.
4. Loss of going concern value, goodwill, or livelihood, where a business cannot relocate without a substantial loss of its patronage; or the loss incurred due to business interruption.
5. Loss of employment due to the relocation or discontinuance of a displaced business.
6. The increased cost necessary to acquire a substitute home, farm or business, or the increased cost of rent for a substitute dwelling or other property.
7. The loss of rental or other income between the time of announcement of a public improvement and the time of taking.
8. Loss of home ownership because of inability to obtain financing within the financial means of the displacee, or the loss of opportunity to continue in business.
9. Loss due to less favorable financing in acquisition of replacement housing.

See: *Mitchell v. United States*, 267 U. S. 341, 69 L. Ed. 644 45 S. Ct. 293 (1925); *United States ex. rel. T.V.A. v. Powelson*, 319 U. S. 266, 87 L. Ed. 1390, 63 S.Ct. 1047 (1943).

Vance cites *Mitchell v. United States*, "States not infrequently directed the payment of compensation in similar [loss of business as a result of taking] situations," and *Joslin Manufacturing Company v. Providence* (a crucial case to impact legislation), which "... is significant in firmly establishing the constitutionality of state legislation which authorizes the recovery of consequential damages."

Justice Holmes (then Chief Justice of the Massachusetts court) spoke of the inequities of compensation law in his much-quoted instruction: "It is not forbidden to be just in some cases where it is not required to be by the letter of paramount law" [*Earle v. Commonwealth*, 180 Mass. 579, 582-83, 63 N. E. 10 (1902)].

CASE FOR FULL COMPENSATION

Full compensation, which is not now a public objective, is necessary, by definition, for fairness. It is also necessary for good transportation network design and construction. When part of the project costs are carried by individuals and groups displaced and disrupted, rather than included in project budgets, network analysis and design will be flawed.

If inaccurate cost calculations will distort networks, they will also distort modal distribution. Therefore, those concerned not with a single mode but with transportation in the large will be particularly concerned that full compensation be achieved.

Similarly, people, whose central concern is not transportation as transportation but those urban land uses that urban transportation exists to serve, will be concerned that inaccurate transportation cost calculation does not distort land development.

An important side benefit of full compensation policy is that it creates the tools for, and the atmosphere for, open and continual discussion of roadway alignments and design with the people most directly affected. Such continual communication is, in fact, necessary to implement full compensation designs.

The East River Drive, one of the most technically difficult highways ever built, is a demonstration of the effectiveness of full compensation in eliciting community consent to public construction that includes expropriation (3). All design and condemnation decisions were discussed with affected owners (the one house that was taken was rebuilt brick-by-brick over the East River Drive, 5 of Miss Anne Morgan's 6 poplar trees

were saved, and she was given 2 Oriental plane trees for the sixth). Little old ladies painted water colors of the highway construction, gave teas for the engineers, and generally behaved differently from the people in the pathway of today's urban Interstate extensions. The experience of the author of this paper is not quite that idyllic. But the record of a large number of public meetings suggests that a direct relation exists between the usefulness of the meeting and the extent to which technicians could promise that all costs would be paid.

The principle is stated succinctly by the American Association of State Highway Officials (4, p. 24): "Agreement can be reached by having representatives of each group participate in the various stages of planning, location and design." Such negotiation and such planning, however, are useless if the objective is simply to determine the "least bad" highway.

It is reasonable to believe the AASHO policy is sound and that most of the problems can be made to disappear if each problem is negotiated with the person or group affected and if it is clear that the objective is full compensation.

RECENT LEGISLATION AND POLICY CHANGES

Full compensation is not only necessary but also operationally practical, and much of the groundwork for policy changes has been laid. This groundwork has been largely initiated by the Federal-Aid Interstate Highway Program, and it may eventually be seen that the Interstate System's considerable technical achievement is exceeded by its contribution to environmental design.

Full compensation for people and institutions displaced is the implied objective of recent court cases and legislation. The Uniform Relocation Act of 1970 and the Highway Act of 1970 would seem to make it possible to compensate all displacees (with the possible exception of small, marginal businessmen and certain tenants).

But the problem of impact on the persons and institutions not displaced but disrupted remains. To compensate for disruption requires that the law define "goods" other than real property and recognize that society is gradually coming to believe that the taking of such goods, both public and private, also should be compensated.

Legal literature is increasingly concerned with compensation. Michelman, in a classic monograph (5), opens his case for "fairness" with an austere dictum from Hobhouse, "... a rational social order cannot base the essential happiness of forty million of men on the misery of one," and a quote from Holmes, "... a government ought not be called civilized if it sacrifices the citizen more than it can help." He decides the 2 positions are commensurate.

Michelman makes the conventional assertion that a government can take property when "... the society is acting rationally in the sense that the new condition of resource employment will produce a greater amount of 'welfare' than the old one did..." and measures a greater amount of welfare by efficiency tests, defining a proposed change as efficient if "... after negotiated compensation has been promised by those who stand to gain from the proposal to those that stand to lose from the proposal, the proposal can win unanimous approval." He, of course, recognized that unanimity is a goal that can be approached but never attained, but he also recognizes the principle of unanimity to be the essential foundation of just compensation.

To define "taking," he first defines "goods": "... all of these land uses are productive of goods which are part of society's sum total of goods: the foundry manufactures are such goods; so is household shelter; so is the use of a neighboring gathering or play space; so is the serenity which emanates from a quiet, shaded street."

FULL COMPENSATION IS PRACTICAL BY DISAGGREGATING BENEFITS AND COSTS

Although the aggregate benefit-cost analysis of networks is important, such aggregate analysis has masked the fact that both costs and benefits are unevenly distributed and that for many individuals and groups the costs are very much larger than the benefits. Therefore, for full compensation, all costs (and benefits) must be disaggregated and distributed accurately by geographic location, by social class (6, 7, 8, 9, 10, 11, 12), and over time (13).

With regard to geographic location, costs will be concentrated within the right-of-way and along the neighborhood edge. Similarly, benefits, such as increases in value of underdeveloped land, will be concentrated near the highway. (But one of the few "value premises" about which there can be no debate is the proposition that any system element that improves the regional transportation system will at the same time reduce average land values in the region.)

Many sources document the distributional effects, by social and economic class, of transportation improvements. That displacement costs bear more heavily on low-income families than on high-income families also is confirmed by their different views of the discount rate. And any transportation element that improves private automobile transportation without at the same time improving public transportation rather automatically increases the transportation costs for all public transit riders in the region.

With regard to time, Wingo states (13):

A plan begins to accrue costs and benefits from the first moment that it influences the behavior of a firm or individual. The total time stream of cost and benefits must be summed up in some fashion and the abandonment of conflicting goals appraised....For the critical question is not only how much the community is prepared to give up to realize the goals implicit in the master plan but who gives up how much so that the fruits of the plan can be realized—quite frequently by others. This perspective has led the uncritical liberal to the implicit conclusion that the importance of the social goals realized by the planned transportation of urban environments always outweighs the current individual and group values which must be foregone. It is by no means obvious that this is the case.

The following is a simple and common example: The taxpayer whose tax rate increases when the right-of-way takes land off the market is often not the same taxpayer who gains, later on, if and when the highway increases the city tax base. A straightforward solution to this tax problem would lend money to communities equal to taxes lost each year by right-of-way taking, the interest and principal payments to begin when the highway is completed.

Full compensation, which requires double-entry bookkeeping in public accounting, also requires institutionalized procedures for calculating and paying disaggregated costs and for calculating and assigning disaggregated benefits. There is a consensus that such accurate accounting is difficult. But it is a basic premise of welfare economics (or of any investment policy) that no investment be made that will not bring a return, in dollars or other benefits. Therefore, a rational society requires that the large number of investors in small amounts of gasoline and excise taxes should show a clear profit on their investment in highways. It is important that this be done. It is even more important that the larger investors—the people investing in homes, businesses, or a way of life—should show a profit on their investments.

Equation 1 given below expresses a basic premise of benefit-cost analysis: The benefits must be larger than the costs to justify the investment.

$$\Sigma (B_u)_n / \Sigma (C_u)_n = 1.0 + (P)_p \quad (1)$$

where

- (B_u) = user benefits,
- (C_u) = user costs,
- (P) = profit rate, and
- $()_p$ = a probability coefficient.

Aggregation is necessary because n is very large; it is reasonable because the individual (B_u) and (C_u) are small.

This discussion includes nonuser benefits (B_{nonu}) and nonuser costs (C_{nonu}) , and the second basic equation becomes

$$[(B_{nonu})_n / (C_{nonu})_n = 1.0 + (P)_p] \quad 1, 2, 3, \dots, n \quad (2)$$

Disaggregation of nonuser accounts is possible because the nonuser n is relatively small; it is necessary because the (B_{nonu}) and the (C_{nonu}) are in many cases very large.

For full compensation to obtain, then, in Eqs. 1 and 2, the rate of profit (P) must be a positive number. [It is common when Eq. 1 is used to require that (P) be relatively large, because $(\)_p$ is likely to be low. However, in Eq. 2, with careful administration of appropriate legislation, $(\)_p$ is likely to approach 1.0 and (P) can be relatively small.]

This is the basis for that more rational public policy that would require, at the minimum, all individuals or groups displaced or disrupted to be "made whole." In fact, they should be overcompensated.

It is apparent that the seemingly utopian view—that displacement should be seen not as a problem but as an opportunity (14)—is rooted in rationality.

The rest of this discussion examines (a) disaggregated costs and benefits by category of impact, using Michelman's more inclusive definition of "taking" and of "goods" [the categories are taken from Section 136(h) of the Highway Act of 1970], and (b) legislation aimed at full compensation. The Highway Act requests information on "the costs of eliminating or minimizing" 17 effects of highway construction. To eliminate or minimize these effects it is necessary, for each category and for each individual and group, first, to determine the magnitude of the effect; second, to calculate the costs incurred and the benefits derived; and, third, to pay the costs (and to collect the benefits) in dollars or in compensation in kind, or to eliminate or minimize the costs through careful and imaginative design.

NECESSARY RESEARCH AND LEGISLATION

These 3 tasks are not easy, but they are far from impossible. The necessary work has been outlined in existing research, most of it either influenced or sponsored directly by the U.S. Department of Transportation, in particular the Federal Highway Administration, and most of the research has been developed in detail.

The straightforward task of abstracting this existing impact research is an activity from which, for small investments, the Department of Transportation would reap large returns. A too cursory summary of this research is (with the direct experience of the author) the foundation on which this paper is built.

The voids in completed, necessary research fall primarily into the following categories:

1. Research on specific problems that might be called "consequential" research. For instance, the distribution of pollutants around a transportation artery generating those pollutants is not well understood. However, methods for attacking this problem exist and are straightforward.
2. Research on how communities function and on the effect of functional change on members of communities (communities being broadly defined as subsectors of urban regions). This fundamental social and environmental research would have significance far beyond transportation planning.
3. Research in regional function and change and, in particular, in different effects of different regional accessibilities. For instance, the differential effects on regional growth of 2 different mixes of private vehicular and public transportation modes is a subject on which much has been said but about which little is certain. As with research in community function, such research would be useful far beyond transportation planning.
4. Research that involves keeping accurate records on the impact of highway construction and other forms of public investment. In fact, such records are essential to most research. There should probably be an independent agency charged with recording impact of the work by the Departments of Housing and Urban Development, Transportation, and Interior and other government agencies. Complete records on the history of displaced homeowners, for instance, would be part of this undertaking.

Table 1 gives a summary of the research necessary to "determine the cost of eliminating" the categories of impact described in the Highway Act.

Although recent legislation has been effective in closing the gap between partial and full compensation for displaced individuals, at least the legislation given in Table 1 by

Table 1. Impact research necessary to determine costs of eliminating or minimizing impacts.

Impact	Research				Legislation					
	Category 1	Category 2	Category 3	Category 4	Category 1	Category 2	Category 3	Category 4	Category 5	Category 6
Pollution										
Air	X	—	—	—	X	—	X	—	—	X
Noise	X	—	—	X	X	X	X	—	X	X
Water	—	—	—	X	—	—	X	—	X	X
Destruction or disruption of										
Man-made resources	—	X	—	X	X	—	X	X	X	X
National resources	—	X	—	X	X	—	X	X	X	X
Aesthetic values	X	X	—	X	X	—	X	X	X	X
Community cohesion	X	X	—	X	—	—	X	X	X	X
Availability of										
Public facilities	—	X	—	X	—	—	—	X	X	X
Services	—	X	—	X	—	—	—	X	X	X
Adverse employment effects	X	X	X	X	—	X	—	—	—	X
Tax losses	X	X	—	X	—	X	X	—	—	X
Property value losses	X	—	—	X	—	—	X	—	—	X
Displacement of										
People	—	X	—	X	X	X	—	X	X	X
Businesses and industries	—	X	X	X	X	X	—	X	X	X
Farms	—	—	—	X	X	X	—	—	X	X
Disruption of desirable										
Community growth	—	—	X	X	—	—	X	X	X	X
Regional growth	—	—	X	X	—	—	—	—	X	X

X = research necessary to clarify impact or legislation necessary to correct or pay for impact.

categories that are discussed below is necessary to make full compensation possible for individuals not displaced but disrupted. [It can be seen from the first legislative proposal (suggesting "negotiated takings") that it may be essential to make impact legislation operational, so that full compensation for displaced owners will be possible.] The objective of all such legislation should be identified as being full compensation of all consequential damages; that is, all public project costs should be carried not by individuals and groups displaced and disrupted but as part of project budgets. The legislative categories are described in the following.

1. An "impact zone" should be recognized that bears a relation to disruption that the right-of-way bears to displacement. It might be defined in various ways: a fixed distance from the pavement edge, say $\frac{1}{2}$ mile, or different fixed distances for different impacts (noise, air pollution, visual environment, second order traffic impact, or community cohesion). The impact zone might be set in each case by the highway building agencies and the community planning agencies. The real "zone" clearly will vary with the impact. For most impacts, a practical zone would include only properties adjacent to the right-of-way (16).

Matheson (16) describes 3 types of excess condemnation authority:

...depending upon the situation of the land and the purpose of the condemnor: (1) protective, (2) remnant, and (3) recoupment. In protective condemnation, the condemnor acts to protect the utility, safety, and beauty of an improvement by taking adjacent land, often for resale to private persons on condition that future owners refrain from injurious uses of the property. In remnant condemnation, the condemnor needs only a portion of a parcel for an improvement, but takes the entire parcel to avoid leaving a useless remnant or the payment of severance damages. In recoupment condemnation, the condemnor takes land benefited by the proposed improvement to recoup the value of such benefits through resale to private persons.

He states that the definition of "public use" is becoming more inclusive:

...as the need for governmental involvement in private activities began to expand, many courts began to accept as "public" any use which substantially contributed to the general utility and facilitated the achievement of public purposes, even though private interests might incidentally benefit from the process. [In *Redevelopment Agency v. Hayes*] ...the court appeared to accept the proposition that the beneficial effect of the taking rather than the actual use of the property after taking might justify condemnation.

...in accordance with the present thinking of California courts on the general problem of public use, it would seem that excess condemnation is valid where the public will derive such a benefit from the contemplated private use, or from the taking itself, that any private benefit can be regarded as "merely incidental."

Matheson recommends single, uniform provisions for protective and remnant takings:

The protective section should provide for: (1) protective taking authority for all condemnors without distance limitation, (2) judicial power to inquire into the necessity of all protective takings for the purpose of resale, and (3) a right of first refusal by the condemnee on dispositions of excess land by the condemnor. The remnant section should provide for: (1) remnant-taking authority for all condemnors for physical and "financial" remnants and in all other cases where "excessive" severance or consequential damages are threatened, (2) a post-verdict election for condemnors between the taking of the entire parcel or only the part needed, (3) a post-verdict election for condemnees to avoid the taking of the entire parcel through the waiver of any "excessive" damages, and (4) judicial power to inquire into the necessity of all remnant takings for the purpose of resale.

Legislation should permit negotiated takings of real property, with all relocation benefits, within the impact zone; that is, if the owner wants to be taken, he should be taken. Such action has several times been upheld by courts (15). According to Strobin (15):

It is to be noted, however, that statutory provisions expressly or impliedly requiring the consent of the owner to the excess condemnation have been recognized to be within the power of the legislature. In the following cases [5 such cases are listed], the right to take an amount of property admittedly not needed for the particular improvement was looked upon with approval by the court where either the statute expressly or impliedly required consent to the taking, or the owner manifested such consent....

It is the advantage of the "negotiated taking" rule that the question of impact would be settled by the owner; if the assertion is correct that, given the will to do so on the part of the agencies, displacement can be fully compensated, the informed owner (16) is bound to break even. The highway building agencies, in turn, would be able to take advantage of the increase in values that the highway brings to the property; if there is a decrease, the losses will be put on project budgets where they belong. Given this form of compensation, the exact limits of the impact zone are not critical, and "a fixed distance from the pavement edge" would probably be a useful definition.

2. Specific consequential damages to persons and properties, whether displaced or not displaced but left in the impact zone, should be paid. Such legislation should list damages and include administratable formulas for paying them. A way of paying for compensation for loss of goodwill, for instance, is described in the Harvard Journal of Legislation (17).

Goodwill itself is by definition the extra income a business receives over and above the return that would be expected on its physical assets. In compensation for the loss of goodwill, the object should be to replace the loss with a similar stream of income. This stream of income can only be replaced by compensating the owner with a lump sum which will return an amount of interest equal to the loss.

The Act suggests formulas for compensating both owners who permanently discontinue business and owners who continue. It establishes maximum payable damages.

It would be an unreasonable hindrance to eminent domain proceedings to permit an injured business with negligible physical assets to receive damages under this act in excess of ten times its average earnings prior to the taking. On the other hand, it would be unreasonable to limit an injured business with considerable physical assets and relatively small average earnings to a recovery less than an amount equal to the value of its physical assets. By establishing a maximum this section protects the interests of the condemning authority; by making the maximum the greater of ten times the average earnings of the injured business or an amount equal to the value of the physical assets of the injured business this section protects the interests of the injured business.

And a lump sum settlement, say 5 percent of "fair market value," should be awarded to all residential properties abutting the right-of-way, but within unacceptable noise zones or unscreened from the highway. [Joslin Mfg. Co. v. Providence, 262 U.S. 668, 67 L. Ed. 1167, 43 S. Ct. 684 (1923) authorizes recovery for various consequential damages, including "damages due to the decrease in value of lands not taken, but contiguous to lands taken"; (15).]

3. Section 319 of the Highway Act should be implemented and made operative in urban areas to heal the "aesthetic" problem of the roadway and community edge; that is, up to 3 percent of construction costs should be provided out of the Highway Trust Fund for environmental design (dense tree masses, strip parks, parcel remnants, extended takings, walls, earth mounds, irrigation, and the like). Design procedures and specific designs should be developed and applied automatically in the same way that street trees are planted along city streets. Useful models exist including those for early urban freeways such as the George Washington Parkway, the Merritt Parkway, certain California urban freeways, and standard design elements of the Chicago Cross-town Expressway.

4. Scarce commodities displaced should be replaced in kind. The definition of a scarce commodity (housing in a tight housing market, parks in densely built-up neighborhoods, or historic landmarks) should be made by the Secretary of Transportation. Related legislation should permit owners of private property as well as of public property to have the option of payment in (a) fair market value or (b) a "functionally equivalent replacement," as termed by Allard (1, p. 355), who states, "...jurors are more conscious of the various elements of damage inflicted... [and] although they are instructed by the courts that fair market value is the measure of just compensation, jurors apparently consider replacement value as a more accurate measure." This principle is, for taking of public property, well established by recent court decisions [United States v. Certain Properties in the Borough of Manhattan, 403 F 2d 800 (1968), and State Road v. Board of Park Commissioners, West Virginia, S. E. 2d 919 (1970)]. The Certain Properties decision states that when a public facility is taken the public agency is entitled to "...the cost of a functionally equivalent substitute ... [if]... structure is reasonably necessary for the public welfare..." and the State Road decision asserts "...where undisputed evidence showed that Board of Park Commissioners was required to acquire substitute land in order to operate park as it was operating before taking, Board of Park Commissioners was entitled to recover cost of replacement land."

5. To determine the "... costs of minimizing or eliminating... disruption of desirable community and regional growth..." transportation planning moneys should go directly to city and regional planning agencies to develop community planning frameworks for all transportation projects. Such costs are currently provided in various ways but on a somewhat random basis. The practice should be institutionalized.

6. A small percentage (say 10 percent) of the Highway Trust Fund should each year be set aside for discretionary use. The rest should be returned directly to that state and to that Standard Metropolitan Area that generated it. The Trust Fund should be continued indefinitely on this basis, and matching shares should be used by the "taxing unit" (state or SMA) with wide discretionary powers, particularly the matching shares.

Payment and design decisions will always vary somewhat, depending on the administering agency. The very different objectives of rural and urban roadway planning are likely to be best implemented by engineers and planners directly responsible to the political representatives of the "user" and "nonuser" clients of the roadways, that is, to state agencies in the case of rural roads and urban agencies in the case of urban roads.

Responsibility for the community participation and approval process would then also fall where it belongs: on those urban political bodies representing the communities.

COSTS OF FULL COMPENSATION

A concern of administrations charged with managing the large public investments in urban highways must be with specific costs of full compensation. Although a number of recent projects suggest that the costs can be very high, the data are fragmentary, often privileged, and controversial. But an instructive case study was the subject of a research project (18) conducted by a group of advanced post-graduate students in the Harvard University Graduate School of Design, with the assistance of professors of urban design, transportation engineering and traffic, planning, and law, and with important help from the Massachusetts highway agencies. The work has been described by this author (19):

...Two Boston Corridors, one about two miles from the center of the city and one about five miles from the center, connecting two radial expressways (the Massachusetts Turnpike and the Route Two Extension) about two and a half miles apart, were assumed as given. It was assumed that network efficiency would be insensitive to exact highway location and design within each corridor and that therefore the selection of a best alignment within each corridor was purely a community planning and investment cost problem.

It was the objective of this study to determine the full compensation costs of each alignment and, if possible, community benefits.

The inner corridor A is bordered on the east and south by the Charles Basin. Massachusetts Institute of Technology lies along the basin and is separated from an industrial zone to the northwest by a railroad. Neighborhoods are fine, dense, stable, low and middle income areas. Commercial properties are located primarily on two east-west arterials.

The western corridor B is bordered by the Charles River on the south. A vacant arsenal and large vacant industries and land fill lie north of the Charles, then several thriving industries, scattered small, stable ethnic neighborhoods, then somewhat higher income, low density neighborhoods, then Fresh Pond Reservoir surrounded by open land and, to the north of Fresh Pond, scattered commercial, open land and land fill.

Costs beyond conventional costs included in corridor accounting: tunnelling under the Charles Basin, moving and lowering the subway for depressed alignments, because of a tight housing market house reconstruction on a one to one basis, replacement of all institutional takings, compensation for homes left in noise zones, reconstruction of arterials with added traffic loadings, special job retraining and compensation costs for highly skilled elderly workers, disruptions costs for businesses and homes during highway construction, special costs for special highway design, costs of replacement parkland, joint development costs where such costs are compensation for takings.

A development model was prepared [this work was done by David Betanger of the Harvard Graduate School of Design] to calculate minimum and maximum added development values and minimum and maximum added tax gains (or losses). It was recognized that this would partly measure only a redistribution of investments within the urban region. But the calculations give a first approximation of tax gains to the communities most directly affected by the highway, and of large increases in private value due to the public investment. These private "windfalls" might be further taxed—the other side of the "full compensation" coin.

Four alignments, A1, A2, A3, and A4, with many variations, were analyzed in the eastern (inner) corridor. One alignment, B1 with variations was analyzed in the western (outer corridor).

Data describing A2 (the "best" inner alignment) and B are as follows:

<u>Community Costs and Benefits</u>	<u>Alignment A2</u>	<u>Alignment B</u>
Costs		
Homes taken	114	130
Jobs taken	7,350	345
Dollar cost	\$151,000,000	\$74,000,000
Benefits		
Development gains		
Minimum	\$ 27,000,000	\$140,000,000
Maximum	\$223,000,000	\$400,000,000
Direct tax gains		
Minimum	\$1,000,000	\$5,000,000
Maximum	\$6,000,000	\$13,000,000

In this bookkeeping the full value (as calculated by these investigators) to the owners of the homes taken (as calculated by the investigators) and the full value of the jobs taken are included in "dollar cost." The costs are the aggregate cost of the link; benefits are disaggregated. Therefore, they are not directly comparable. "Tax gains" assume a discount rate of 10 percent. Clearly the local benefits of alignment B are very high.

Several related outcomes of this analysis are instructive:

1. The costs, while approximate, suggest that the price of full compensation in dense urban areas is very high. The cost of the only acceptable inner alignments is so great (about \$60,000,000/mile) that the system benefits from this link must be very high to justify its construction under any circumstances. [Earlier professional studies of the inner cor-

ridor were hobbled by inflexible constraints on "fairness," with predictable results: the "best" highway as judged within such constraints was opposed by individuals and communities unfairly treated. But these early studies laid the problems bare and therefore prepare the way for their solution.]

2. Full compensation has, in this case, a dramatic effect on the network design, pushing the first circumferential far away from the Central Business District. This can be expected; because the area further away from the center is less densely built up, right of way and other compensation costs are reduced; because there is more undeveloped and underdeveloped land, the development potential, in this case, is greater.

This analysis supports professional studies suggesting that full compensation costs are very high, probably \$40 to \$50 million a mile for 8-lane expressways in dense urban areas. If these figures are accurate, grade-separated freeways in densely built-up areas are likely to be among the "marginal" links in any regional transportation network. Incremental network benefits must be large to justify these link costs.

The discrepancy between payments for displacement and disruption and true value may explain why a society involved in a passionate love affair with the private automobile is at the same time incensed by the construction of urban expressways. Highway engineers and other urban technicians have taken the brunt of this anger. But it is the institutional structure that is out of kilter, and it is this institutional structure that must be remodeled. A beginning to this remodeling has been a major contribution of the urban highway building process. The Interstate Highway Acts and the 1970 Relocation Assistance Act have done much to correct inequities in expropriation law.

But much remains to be done. Michelman, in a classic legal monograph states it succinctly: "... any measure which society cannot afford... or is unwilling to finance... under conditions of full compensation, society cannot afford at all."

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STUDY OF THE IMPACT ON HOUSEHOLDS OF RELOCATION FROM A HIGHWAY RIGHT-OF-WAY

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Interviews taken at 228 households displaced by right-of-way acquisition for Interstate 90 on the west side of Cleveland were analyzed to study the effects of relocation. The 228 interviewees were included in a random sample of 730 households drawn from the 2,333 families that had been relocated for this project. Independent variables considered were age, income, occupation, education, and anomia, a social psychological measure of attitude. A sufficient number of black households were not available to consider the influence of race on the relocation experience. Unfavorable attitudes toward relocation were found to attenuate with time at a rate inversely proportional to age and length of residence at the pre-relocation address and directly proportional to income and educational attainment. Relocates displayed the same tendency to maintain or upgrade the social status of their neighborhoods as did an independent sample of voluntary movers. Median monthly housing expense increased by \$52.50 after relocation. More than half of those who had been tenants became owners after relocation. Only 5 percent of the relocates changed jobs because of being relocated, and a third made longer trips to work. The impact of relocation impinges most heavily on the poor and the elderly, if such impact is defined as the total expenditure of economic, physical, and psychic resources necessary to adjust to a new residence and location.

• ACCESSIBILITY to economic and cultural opportunities is a necessary condition for a healthy society. Until comparatively recent times highway builders were comfortable in the assumption that they were contributing to social welfare by improving the mutual accessibility of points in physical space. Highway engineers are shocked and dismayed to find the validity of their traditional decision-making processes questioned by protest groups from urban areas (1, 2). Fellman, a sociologist, grants the good intentions of highway planners (2) but charges them with negligence in understanding the nature of neighborhoods and the individual feelings and problems of neighborhood residents. Within the past decade strong citizen reaction against proposed urban freeways has developed from San Francisco to Washington, D. C., and from Cleveland to New Orleans.

The traditional standard of economic efficiency in highway location and design has been the "benefit" to highway users as compared to the "cost" of the project including purchase of right-of-way. Both cost and benefit have been considered from the viewpoint of the accountant. That is, cost and benefit are defined respectively as amortized expenditures by the highway agency and annual operating cost savings by highway users, based on operating costs prevailing prior to a proposed improvement. Although the application of the so-called benefit-cost ratio by no means guarantees that the minimum cost location will be selected in any given instance, there has been a tendency, as De Leuw (3) notes, for engineers to emphasize low construction costs and minimize right-of-way costs. De Leuw attributes this tendency to long experience of highway organizations with limited budgets. It is also well to remember that the highway construction program was for many years located largely in the rural areas where maximizing the

number of miles of pavement built annually was regarded generally as a socially desirable goal.

Unfortunately neither highway costs nor benefits are uniformly distributed among the population. Location of an urban highway in accordance with a benefit-cost ratio in its traditional form virtually ensures that the route will traverse areas containing low-cost housing inhabited by people relatively low on the socioeconomic scale. Because access to private automobile transportation is a monotonically increasing function of income, this means that the burdens of relocation must often be borne by that segment of the population least likely to participate in the benefits of the highway improvement that displaces them. In an era when differences are already all too apparent between life styles and opportunities of the poor and those of the affluent, the displaced household may perceive a further incursion upon its domain by an "improvement" primarily for the use of others.

It is important to realize that the social and economic climates in which current urban projects are being performed are entirely different from conditions that prevailed in former times when roads were welcomed by rural people as a way out of enforced isolation. We must face the "relocation dilemma" as it has been labeled by Smith (4). The renewal of our cities requires among other things an effective transportation network. Whatever may be its merits as an urban transportation vehicle, the private automobile is surely an important factor in the American economy. Furthermore, the automobile has acquired a unique importance not related to its primary function. The automobile frequently serves as a symbol of wealth, status, and power. It would seem in fact that this unique love of man for machine would tend to offset carefully constructed rational arguments about the disadvantages of the automobile or the desirability of alternative modes of intraurban travel. It is, therefore, to be expected that the private automobile will retain its primacy as an urban transportation mode for the foreseeable future. Given the inadequacy of a street system conceived in most large cities before the ascendancy of the automobile, it will therefore continue to be necessary to develop the urban highway network. Such construction is essential to provide physical accessibility. On the other hand, the destruction of dwellings in crowded cities already beset by housing shortages cannot necessarily be dismissed as an unavoidable evil essential to progress. Disruption of the lives of thousands of individuals must be given due consideration.

The Federal-Aid Highway Act of 1968 was the first substantial legislative effort to alleviate the economic impacts of enforced relocation for highway construction. Although the implementation of this act has done much to relieve financial burdens on relocatees, it would appear that existing legislation does not sufficiently recognize that financial problems are not the only hardships that result from relocation. Especially among the elderly, the necessity for social and psychological adjustment to new surroundings can be a process so difficult that some relocatees have attributed to it serious illness, or even death of a spouse.

There must thus be added a new dimension to highway engineering decisions. As Smith (4) suggests, social costs must be included in the accounting of project costs and benefits. Smith recognizes that the true social cost of a route through a neighborhood containing "better quality" homes may be less than that of an alternate where property acquisition costs may be lower. The political implications of such a decision are clear to any experienced highway official. In an era when protest and confrontation seem to be increasingly commonplace means of exercising political power, the real problem of the highway official may well be to develop rational, equitable plans amid the tumult and the shouting. One thing is clear: Today's highway engineers and administrators must possess a far deeper understanding of people and their problems, particularly those problems that result when one is uprooted from one's home for the benefit of the community.

More specific, it is incumbent on highway engineers and administrators to learn more about social costs or nonuser effects generated by urban highway construction and to have 2 important goals in mind:

1. The long-range objective of incorporating into location and design decisions a realistic evaluation of adverse social effects of proposed projects so that alternatives

can be compared on the basis of total social cost; and

2. The immediate objective of finding ways to improve the processes of property acquisition and relocation of residents to minimize adverse social, psychological, and economic impacts on persons directly affected by these processes.

This paper describes information collected and conclusions reached in an attempt to contribute to the achievement of this latter objective.

DESCRIPTION OF THE STUDY

There were 2 principal data sources employed for this study of residential relocations from the right-of-way of the proposed route of Interstate 90 on the west side of Cleveland. One such source was the collection of case records in the files of the Ohio Department of Highways. Data on 730 households were extracted from those files. This sample was selected from among the 2,333 households displaced by purchase of right-of-way for construction of I-90 between West 160th and West 25th Streets in Cleveland, together with approximately 200 households similarly displaced for construction of I-71 in the vicinity of West 130th Street.

Clearance of right-of-way for portions of the I-90 project was begun about 4 years prior to the study. Right-of-way acquisition was still in progress, but most of the households had been relocated for a period ranging from 1 to 4 years at the time of the study. No construction had been undertaken on the I-90 project between the Cleveland corporation limit and West 25th Street, a distance of about 6 miles. Some construction was in progress in the neighboring municipality of Rocky River, which abuts the city of Cleveland on the west. I-71 was complete and open to traffic throughout the Cleveland metropolitan area. Relocation of households from the I-71 right-of-way was completed about 6 years prior to the study.

Names of relocatees along I-90 indicated the presence of a wide variety of ethnic backgrounds. There are, however, few Negroes on Cleveland's west side and none among the relocatees from I-90. The I-71 study area was selected to include some black relocatees in the investigation. This area was not a completely black neighborhood, and most of the black households had relatively high incomes; but there was no other location in the Cleveland metropolitan area that offered a better opportunity for study. The great majority of Negroes in Cleveland are situated on the east side, where freeway development has been virtually halted.

The 730 households, all of whom moved before the provisions of the 1968 Federal-Aid Highway Act were in effect, were grouped in 10 clusters. It has been pointed out that the neighborhood on I-71 was selected for its ethnic characteristics. Fifty property parcels were randomly selected from this region. Another cluster of 50 parcels was randomly selected in the suburban community of Rocky River because there was no other portion of the proposed I-90 alignment possessing a substantial group of single-family residences valued at more than \$30,000. A third randomly selected cluster of 50 parcels was located in the vicinity of West 25th Street. This region contains a Puerto Rican community and a transient, low-income population including a high proportion of individuals.

The remaining 7 clusters of property parcels were chosen by dividing the I-90 alignment between Rocky River and West 25th Street into 26 segments, each about 1,000 ft long. Each 10-station segment embraced from 2 to 5 city blocks, depending on the freeway orientation, and included from 40 to 75 property parcels. The clusters to be sampled were randomly selected from the 26 segments just described. A table of random numbers was employed in the selection of all clusters to ensure randomness in the mathematical sense of the word.

The principal source of study data was a survey that resulted in 228 completed interviews of households from among the 730 originally selected from the random sample. Interviews were conducted by Cleveland State University students.

A low percentage of successful contacts was anticipated from the experience of other relocation studies. House (5) reported 55 percent success in attempts to contact 81 families displaced from a Milwaukee expressway project, and Rudolph (6) was able to interview 68 percent of 130 households displaced from an urban renewal project in

Akron, Ohio. Thursz had available a population of 186 households for his study of relocation from an urban renewal project in southwest Washington (7). He completed 98 interviews or about 53 percent and noted that many of the households not contacted could not be located even though addresses had been obtained.

The 496 names of relocatees listed in current Cleveland directories were the portion considered "available for interview" out of the total random sample of 730 relocatees. It was anticipated that a success rate of about 50 percent would yield the desired 250 interviews for an approximate 10 percent sample.

Interviewers made a total of 330 personal contacts with relocatees or with former neighbors or employers of relocatees. There were 45 relocatees who refused to be interviewed, and 27 cases in which former neighbors or employers had no knowledge of the current address of the relocatee. There were, in addition, a number of relocatees who were not home on the occasion of 3 visits to their homes. The number of completed interviews was thus about 69 percent of the personal contacts made and about 46 percent of the total of those available for interview. About 83.5 percent of relocatees with whom contact was made agreed to be interviewed.

Attempts were made to describe attitudes of relocatees as functions of 5 basic variables: age, income, occupation, education of household head, and score of household head on the Srole anomia test, a well-known instrument used by social psychologists. Design of the interview schedule was adapted from that used by Thursz (7) in his southwest Washington urban renewal study. It was hoped that data and results will thus be sufficiently comparable to those of earlier work to contribute something to the development of urban planning theory even though the present study was designed primarily to inform highway officials and to assist them in their day-to-day operations.

CHARACTERISTICS OF THE SAMPLE

Certain comparisons with 1960 census data are possible and indicate the degree to which the sample of relocatees was representative of the population in the census tract of origin. Because some relocatees were moved in 1965 and many were moved in 1966, the use of 1960 census data is not so misleading as it might appear. In any case, no 1970 data were available in time for the study.

Table 1 gives comparative statistics for the census tract of origin, the total random sample of 730 households, and the 228 households interviewed. It is apparent that the total random sample and the group of 228 interviewees are not significantly different in socioeconomic characteristics. Data given in Table 1 indicate that the relocatees are somewhat better educated than the general population in the tracts from which the relocations originated. There is, however, a better agreement between the proportions of those who finished high school than between the proportions of those who completed fewer than 8 grades. About 9.6 percent of the household heads interviewed completed 4 or more years of college. Analysis of data for the census tracts also shows that about 9.6 percent of the total tract population completed at least 4 years of college. It is inferred that the more education one has, the more likely one is to respond to a survey questionnaire.

The U.S. Bureau of the Census defines a person of foreign stock as one who was born outside the United States or one who has at least 1 foreign-born parent. Relocatees were asked whether the head of the house, his father, or his grandfather was foreign born. No comparable data were available from state relocation files. The proportion of the total population of foreign stock can be computed from census data. Results of survey of relocatees include the percentage who had foreign-born household heads, fathers, or grandfathers.

In every tract but one, the median number of rooms per dwelling unit in the current residences of relocatees was larger than the corresponding figures for the census tracts from which the relocations originated. It is apparent that a general improvement has occurred with respect to the size of dwelling units.

The proportion of homeowners among the interviewees was about the same as the corresponding proportion in the census tract of origin. But homeowners are really overrepresented in the group interviewed. For the 730 households in the total random sample, state records show that 58 percent were owners at the pre-relocation address and 42 percent were tenants. The explanation for this discrepancy would seem to be

that tenants are more mobile than homeowners. Relatively more tenants than owners may thus have moved from the Cleveland area or could not for some other reason be located for interview. Relocates living in apartment houses equipped with telephones in the lobby and electrically operated entrance doors seemed to find it easier to refuse to be interviewed than did those prospective respondents with whom face-to-face contact was possible.

ECONOMIC ASPECTS OF RELOCATION

Median monthly payment being made by relocatees who owned their current residences was about \$132.50. Median rent being paid by tenants in their current location was about \$93.50. Four-fifths of the relocatees stated that their current monthly costs were more than they had paid before being relocated. The median increase of new over old monthly housing expenses for relocatees interviewed was \$52.50.

About 39 percent of the 730 state relocation files sampled contained information on monthly housing expense prior to relocation. For this group of about 285 relocatees, median monthly housing expense (either rent or mortgage payments) was approximately \$79 per month. A total of 131 relocatees paid less than \$75 per month prior to relocation, while only 14 of those interviewed paid less than \$75 per month for their current residences.

Median sale price for new dwellings purchased by relocatees was about \$19,200. Median down payment was about \$13,300. Slightly more than half of the relocated homeowners reported that they were entirely satisfied with the prices paid by the state for their old dwellings.

Relocation seems to have had little effect on employment situations. Sixty-eight percent of the relocatees interviewed stated that they had not changed jobs since being relocated. Of those who had changed their employment, nearly nine-tenths reported that the change was not connected with relocation. Five percent of the relocatees who changed jobs did so because their old jobs were too far from their new dwellings.

One-third of the relocated household heads reported that their trips to work took longer than trips to work prior to relocation. One-quarter stated that their present work trip is about the same duration as it used to be, and about 17 percent said they take less time to get to work than they did before being relocated. Approximately 13 percent had retired since being relocated, and about 1 percent said they were unemployed at the time of their interviews. The remaining interviewees were not sure about the time required to get to work or failed to answer the question.

The predominant change in tenure was from tenant to owner. Over half of those relocatees who were tenants became owners after they were relocated. Only about 10 percent of the relocated homeowners became tenants after relocation, but a few elderly owners moved in with relatives or into institutions.

Tenants were generally younger than homeowners. Fifty-eight percent of the relocatees who were originally tenants were under age 45, while only 20 percent of those who were originally homeowners were under age 45. Furthermore, the tenants seem to have been somewhat more affluent. Two-thirds of the tenants earned \$100 per week or more in take-home pay, while the corresponding proportion among relocated owners was only 49 percent. Actual income differences between relocated tenants and owners may be less than these figures indicate because tenants were somewhat underrepresented.

The inference seems clear, however, that the relocation experience provided an impetus to buy a house among many young families financially able to do so. It is in this sense that relocation is sometimes viewed as a benefit. An improvement in the residential facilities of a household is a benefit, provided that the household can afford such an improvement. There were cases where an enforced move seemed to provide the incentive that a family required to obtain the more desirable residence it needed and could acquire without financial hardship.

ANALYSIS OF MOVING BEHAVIOR

A total of 638 "permanent relocation" addresses could be obtained from the random sample of 730 relocatees. Inspection of spot maps similar to the one shown in Figure 1

indicated that the pattern of settlement after relocation was anything but random. Mathematical analysis of these spot patterns also demonstrated this lack of randomness.

Visual inspection of the spot maps made it clear that relocatees tended to settle in the immediately surrounding area. Those who did move more than a mile from their old homes generally moved to one of the western or southwestern suburbs of Cleveland. Few relocatees crossed the Cuyahoga River and its contiguous industrial areas to settle in east-side residential areas. Westsiders they were, and westsiders an overwhelming majority remained.

An insight into the decision processes of the relocatees can be gained by an analysis of the social status of their census tracts of origin and destination. Only the moves that resulted directly from the relocations were considered because data were not available on a sufficient number of subsequent moves.

Each of the 127 census tracts containing one or more relocatees was assigned a socioeconomic rank score in accordance with the Farber-Osoinach method (8). This method has been shown to correlate well with the Shevky-Bell Index of Social Rank and is very much simpler to compute.

Scores are assigned in accordance with the following 4 criteria:

1. Percentage of white-collar workers (census categories 100 to 400),
2. Median school years completed,
3. Median income, and
4. Percentage of nonwhite persons.

The Farber-Osoinach Index of Socio-Economic Rank ranges from a minimum of 0 to a maximum of 10. These ranks were then used to assign each census tract to a social-status category from 1 to 5. Category 1 possesses the highest social status and category 5 the lowest.

Each of the 638 moves that could be traced through state records was then identified with a point in a social-status space defined by the variables from category i and to category j. There resulted a 5 by 5 matrix of moves (Table 2). Data given in Table 2 have been "normalized" to form a stochastic matrix in which all rows sum to 1 and may, thus, be regarded as a matrix of conditional probabilities. That is, each number represents the probability that a family moved into a tract belonging to social-status category j if it is known that the family moved from a tract in social-status category i.

Data given in Table 2 show a relatively heavy concentration on the main diagonal and generally larger numbers in positions below the main diagonal than in corresponding positions above it. This situation indicates a tendency for relocatees to select a new residence in the same social-status category as their original homes or to upgrade their residential status. Two hypotheses could thus be offered to explain the residential selections of relocatees:

1. Relocatees tend to select new residences as close as possible to their old homes; and
2. Relocatees tend to move to new areas having a social status equal to or higher than that of their old areas, provided they are financially able to do so.

A similar matrix of conditional probabilities was developed from data on 507 voluntary moves in Toledo, Ohio. These moves were voluntary in the sense that they were known not to have resulted from right-of-way acquisition. The origins and destinations of the moves in Toledo were taken from a 10 percent random sample selected from the pages in the 1967 Toledo telephone directory. Addresses in this sample of 41 pages were compared with addresses in the 1968 directory for persons whose identity could be established unambiguously. Social ranks of the Toledo census tracts were assigned from a study of structural condition of the residences, as determined by the Toledo-Lucas County Plan Commission in an area-wide survey in 1967. The system of social ranking was based on the percentage of dwellings in a census tract in need of major repairs or in a dilapidated condition. A high correlation ($r = +0.6$) was found between social ranks based on structural condition and Shevky-Bell Index of Social Rank computed from 1960 census data. The extent of the similarity between the relocation and the voluntary moves can be appreciated by computing the row means and variances. The results of these computations are given in Table 3.

Table 1. Selected characteristics of sample of relocatees.

Characteristic	Census Tract of Origin (avg)	Total Random Sample ^a	Interviewees ^b
White-collar workers, percent	51	23	23
Retired, percent	N. A. ^c	17	18
Currently employed, percent	N. A.	67	68
Finished fewer than 8 grades, percent	16	N. A.	6
Finished high school, percent	25	N. A.	30
Foreign birth or stock ^d , percent	33	N. A.	43
Median age of household head, years	N. A.	51.5	54
Homeowners, percent	70	N. A.	75
Median weekly take-home pay, dollars	N. A.	N. A.	131.5

^aN = 730.
^bN = 228.
^cNot available.
^dThe U.S. Bureau of the Census definition of foreign stock differs from that used in this study.

Figure 1. Typical spot map.

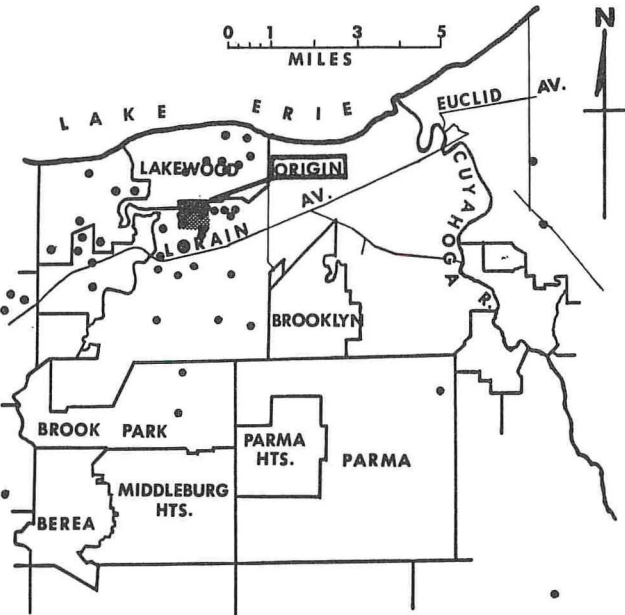


Table 2. Probability of moves of 638 relocatees from one social-status space to another.

Social-Status Category Moved From	Social-Status Category Moved to				
	1	2	3	4	5
1	0.315	0.329	0.198	0.096	0.062
2	0.179	0.589	0.179	0.052	0.001
3	0.055	0.354	0.494	0.042	0.055
4	0.017	0.195	0.363	0.274	0.151
5	0.039	0.073	0.203	0.148	0.537

Table 3. Comparison of relocation and voluntary moves.

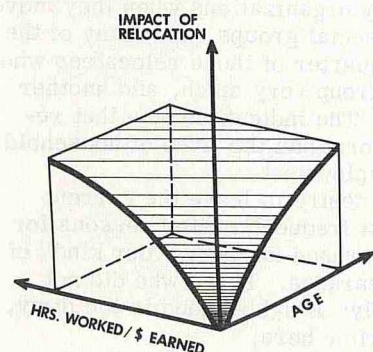
Social-Status Category Moved From	Mean of Social-Status Categories Moved to		Variance of Social-Status Categories Moved to	
	Relocation	Voluntary	Relocation	Voluntary
1	2.26	2.21	1.40	1.22
2	2.10	1.96	0.56	0.78
3	2.69	2.62	0.74	1.15
4	3.35	3.20	1.02	1.05
5	4.07	4.21	1.39	0.64

Table 4. Attitudes of 228 relocatees toward moving.

Attitude	All Relocatees (percent)	Relocatees With Some College (percent)
Initial		
Strongly disliked having to move	60	56
Somewhat disliked having to move	15	17
Did not care much one way or other	14	20
Somewhat pleased	7	0
Very pleased	4	7
Total	100	100
Present		
Very sorry we had to move	33	22
A little sorry	19	18
Do not care much one way or other	12	10
A little happy	20	30
Very happy	15	20
No opinion	0.4	0
Total	100*	100

*Rounded.

Figure 2. Schematic representation of impact of relocation.



The same tendency toward upgrading the social status of one's residence exists among relocatees and voluntary movers. The similarity of the row means is particularly striking. It seems reasonable to conclude that social-status considerations are equally important to relocatees and to voluntary movers. Although 40 percent of the relocatees interviewed felt that they were not given enough time to find a new residence, it may well be asked whether locations selected after a longer search would have been substantially different in character from that of the neighborhoods actually chosen. It also seems worth noting in this connection that three-quarters of the relocatees interviewed expressed a desire to stay in their current neighborhoods.

There were too few nonwhites in the survey sample to permit a detailed study of the effect of race on the impact of relocation. Those black families who were in the sample all originated from a neighborhood traversed by I-71 near West 130th Street. This neighborhood was racially integrated and unique on the west side of Cleveland.

Only 1 black family that remained near the old neighborhood has moved away, but 6 of the 8 black families who moved to the east side of Cleveland have moved away from the addresses to which they were originally relocated. Four of those that had moved away could not be traced. One black family moved from the east side to a western suburb, and the remaining family moved from a predominately black area to a predominately white area on the east side. It appears that the experience of having lived in an integrated neighborhood may have fostered a dissatisfaction with either a predominately black or a predominately white neighborhood. Those who moved to the east side of Cleveland selected one or the other in approximately equal proportions but have displayed a marked tendency to move again.

NEIGHBORHOOD FACILITIES AND SOCIAL LINKS

Before relocation, only 2 in 10 of the households interviewed reported having to travel more than a mile to food stores. More than 4 relocatees in 10 travel more than a mile to food stores from their current addresses. It is probably because a substantial number of relocatees moved into suburban areas that the shopping trip seems to have become longer for many people. Most suburban food stores are located in shopping centers that were designed to be reached by automobile. Longer shopping trips must therefore be regarded as resulting from suburban living and are a consequence of relocation only to the extent that relocation caused some people to select new homes in the suburbs.

Forty-five percent of the relocatees who attend church reported being farther away from their churches after relocation. Six relocatees in 10 still attend the same church. Only 7 percent of the relocatees dropped out of voluntary organizations when they moved. Half the organizations dropped were church-sponsored social groups, and many of the rest were women's clubs other than church groups. A quarter of those relocatees who dropped out of an organization said they missed the group very much, and another quarter said they missed their former group not at all. The indications are that relocation affects the social lives of wives and children more than the lives of household heads who derive many of their social contacts from employment.

One in 5 relocatees interviewed expressed a definite desire to leave the current neighborhood, but 3 in 4 wanted to stay. The three most frequently cited reasons for wanting to stay in the present neighborhood were neighborhood is clean, "our kind" of people live here, and house is well built or of good appearance. Those who did not want to stay cited the following 3 reasons most frequently: Neighborhood is too dirty, we do not like the people here, and there is too much crime here.

When asked what features of their old neighborhoods they missed, more than 3 relocatees in 10 replied "nothing." Another 2 in 10 missed the companionship of friends or relatives, and the others named a variety of neighborhood characteristics. Nearly 4 relocatees in 10 stated that they had nothing in their new neighborhoods that their old neighborhoods did not possess.

If the loss of old friends and the necessity of making new ones is regarded as a measure of the social impact of relocation, there is no doubt that the poor and the elderly are most affected by the severance of social ties that existed in their old neighborhoods. Sociologists have found that low-income families often rely on the extended family as a

source of social contacts and tend not to make friends outside their circle of relatives. Among the relocatees interviewed, those households in which the weekly take-home pay of the head was less than \$100 were nearly 3 times as likely as more affluent households to have made no new friends after being relocated. Households with heads aged 61 or older were about 6 times as likely to have made no new friends as households with heads aged 30 or younger.

AGE, LENGTH OF RESIDENCE, AND ATTITUDES TOWARD RELOCATION

Six relocatees out of 10 said they strongly disliked having to move when they first learned they must be relocated. Only 5 percent of the relocatees were very pleased about having to move.

Three relocatees out of 10 are still very sorry they had to move, but 15 percent now report being very happy about it. Another 20 percent is now a little happy about moving. The very-sorry group has thus been reduced by 50 percent, while the very-happy group has increased threefold with the passage of time.

It was found that length of residence at the pre-relocation address is a more sensitive variable than age in predicting the impact of relocation on a household. The impact of relocation is defined here to mean the net psychological effect on a household of the economic, social, and physical adjustments made necessary by an enforced move. One way to measure such impact is by observing the number of households or individuals who still harbor distinctly negative feelings toward relocation after the passage of an appreciable period of time.

About 60 percent of the relocatees who had resided at their old homes for 11 years or more strongly disliked having to move when they first learned they were to be relocated. Nearly 40 percent of those families are still very sorry they had to move. On the other hand, about 42 percent of the families who had lived at their old addresses for less than a year said they strongly disliked having to move at first. Less than half of this latter group is still very sorry about being relocated. Furthermore, families who had lived at their pre-relocation addresses for less than a year were about $2\frac{1}{2}$ times more likely to like their new homes very much more than relocatees who had lived at their old residences for 11 years or longer.

Households with heads between ages 31 and 60 were more than twice as likely as families with older or younger heads to be very happy about their relocation at the time of their interviews. Family heads in the 31-to-60 age group were likely to be more affluent than their older or younger counterparts. Therefore, families in this age group were in the best position to select more desirable facilities. Many of those who were able to improve their residential facilities now realize that the enforced move worked to their ultimate advantage. The tendency to be very happy about having been relocated was most marked among household heads between 31 and 45 years of age.

INCOME, OCCUPATION, EDUCATION, AND REACTIONS TO RELOCATION

Relocatees who earned at least \$200 per week take-home pay were distinctly more likely than others to be very happy they had to move. Nearly 60 percent of the relocatees in this income group expressed such a sentiment. Relocatees with relatively high incomes are also somewhat less likely to express unfavorable attitudes toward their new homes than those in lower income groups. More than 4 out of 10 relocatees stated that they had more money worries since relocation, but the size of the household's weekly income seems to have no bearing on the incidence of increased money worries.

About two-thirds of the relocatees earning \$101 to \$200 per week in take-home pay expressed a desire to stay in their current neighborhoods. About 80 percent of all other relocatees, those earning \$100 per week or less as well as those earning more than \$200, said they wanted to stay in their current neighborhoods. The comparatively smaller proportion of relocatees making from \$101 to \$200 per week who want to stay in their present neighborhoods may be due to a combination of a desire for upward social mobility and the economic ability to act on such a desire.

Relocatees with professional or technical occupations were markedly less unhappy about their enforced moves than were relocatees in general. Eight percent of relocatees in this occupational category reported being very sorry they had to move at the time of their interviews. The corresponding figure for all relocatees surveyed was 33 percent. Similarly, 25 percent of relocatees with professional and technical occupations stated at the time of their interviews that they were very happy they had to move. About 15 percent of all relocatees expressed similar feelings.

The inference that professional and technical workers are more geographically mobile than the rest of the population seems to be borne out by their expressions of plans to move. Twenty-five percent of this occupational group stated that they had definite plans to move, compared with 14 percent of all relocatees.

Relocatees with some college education were more likely than others to hold a favorable opinion of the state's selection of the route for I-90, which caused their displacement. Although initial feelings of the educated were about the same as those of others, current attitudes toward moving may have been affected by this attitude toward the highway. Table 4 gives a summary of attitudes toward moving at the time relocatees first became aware of the necessity to move.

Relocatees who had attended college were more likely to have developed favorable feelings toward the moving experience. Whether this situation is due to some feeling of satisfaction from having contributed to a civic improvement cannot be answered from the data at hand. Another possible interpretation is that relocatees with some college education were likely to be found in occupations that conferred on them sufficiently high status and income to furnish a wide selection of residences. There would thus be a greater probability of finding a new home that would most nearly conform to their wishes.

ANOMIA AND REACTIONS TO RELOCATION

Robinson and Shaver (9) define anomia as "...an individual's generalized, pervasive sense of social malintegration or 'self-to-others alienation' (vs. self-to-others belongingness)." Thursz (7) describes the Srole anomia scale less technically as an instrument designed "to measure the degree of hopelessness and social dysfunction or disorganization in a selected population." The scale in its present form was devised by Srole in 1956 and consists of a set of 5 affirmative statements, each one intended to measure 1 aspect of anomia. The Srole anomia test was included in the survey questionnaire. (The term is often spelled "anomie" in the sociological literature.)

The test is scored by counting the number of statements to which the subject expresses unequivocal agreement. The score may thus range from 0 to 5, with the higher score indicating a higher degree of anomia. The validity of the test and the results of various investigators are reported by Robinson and Shaver (9). Anomia has been found to be inversely related to socioeconomic status and negatively correlated with occupational status, income, and education (9).

Not all of the relocatees interviewed in Cleveland responded to the Srole anomia test, but 183 complete replies were obtained. Forty-three percent of this group received high anomia scores (3 to 5), and the remaining 57 percent were considered low on the anomia scale with scores between 0 and 2. Some 18.6 percent of the Cleveland relocatees received a score of 0. This group may be compared with the 5 percent reported by Thursz (7), who tested a sample of relocatees from an urban renewal project in southwest Washington, D.C.

Tetrachoric correlations between Srole anomia score and education as well as occupation were each found to be significant at the 0.01 level. The occupation variable was dichotomized as white collar and nonwhite collar, and the education variable was expressed as completed 8 grades or fewer and at least some high school. Relocatees of the white-collar category and those who had completed at least some high school were found to be more likely to score low (0 to 2) on the anomia test. Coefficients of tetrachoric correlation were 0.36 and 0.31 for occupation and education respectively, with standard errors each about 0.11.

Similar correlations were found between anomia and age and between anomia and income. The more affluent were found to be more likely to score low on the anomia

test, as were relocatees under 45 years of age. The general relations reported by Robinson and Shaver (9) were thus confirmed in the sample of Cleveland relocatees.

Relocatees with high anomia scores (3 to 5) were more likely to express definite plans to move from their current neighborhoods ($r_t = 0.31 \pm 0.11$). These same relocatees were also less likely to feel that they "belong" in their current neighborhoods ($r_t = 0.25 \pm 0.11$), and less likely to express satisfaction with their current residences ($r_t = 0.24 \pm 0.12$).

High anomia scores were also associated with a greater tendency to disagree with the state's location of I-90, but not to a statistically significant extent ($r_t = 0.17 \pm 0.11$). Relocatees with low anomia were somewhat more likely than those with high anomia scores to be at least a little happy they had to move. This latter relation is not a strong one ($r_t = 0.13 \pm 0.11$).

It thus appears that high anomia is associated with consistently negative attitudes toward the relocation experience as well as toward the current neighborhood and the current residence. In view of the relations that have been demonstrated between anomia and various components of socioeconomic status, it is clear that the social and psychological impacts of relocation will be relatively more severe on the poor, the elderly, and the poorly educated. This condition is shown schematically in Figure 2. Because income is a continuous variable it has been selected as an index of socioeconomic status.

The impact of relocation can be considered for the present purpose as the total expenditure of economic, physical, and psychic resources necessary for a household to attain a satisfactory degree of adjustment to a new residence, including its location and its environmental characteristics. Figure 2 shows that the impact of relocation increases monotonically with age and with the expenditure of time required for the household head to earn a dollar.

FOREIGN EXTRACTION AND REACTIONS TO RELOCATION

Analysis of the data shows that initial and current attitudes toward moving, attitudes toward the new residences and the new neighborhood, and attitudes toward the location of I-90 are not affected by foreign birth or parentage. For practical purposes, the ethnic background of a relocatee has no bearing on his reactions to relocation, provided that the relocated household is white. There were insufficient data available for this study to produce conclusions about the impact of relocation on nonwhites.

REACTIONS TO RIGHT-OF-WAY PERSONNEL AND PROCEDURES

When asked for further comments about their experiences in selling their properties to the state, more than a third of the homeowners expressed dissatisfaction with state employees. Typical remarks were to the effect that right-of-way personnel were not courteous, were pushy about settlement, or harassed tenants.

Treatment by state employees was a primary concern of about 10 percent of the 141 relocatees who accepted the opportunity to offer general comments at the end of the interview. Some people expressed a feeling of pressure to move. Others felt that their special problems were ignored or that they were being treated as if it were their fault that they were in the way.

A public relations effort in the constructive sense of providing information would probably be helpful in preparing relocatees for their ultimate moves. Two public hearings are now required for federal participation in a project, but right-of-way matters may not receive their proportionate share of attention in these hearings.

A possible solution would be to hold a series of neighborhood meetings devoted entirely to matters of property acquisition and relocation. A series of such meetings is suggested because the problems and interests of elderly residents in an inner-city neighborhood would, for example, be different from homeowners in a middle-class suburban community. More active participation by the public relations office of the highway departments may be desirable for the presentations at such neighborhood meetings.

Twenty-six percent of the relocatees interviewed reported that they were offered assistance by state personnel in finding new residences. But assistance in finding prospective homes is not the only kind of help that is sometimes needed. What may be

a routine business transaction to a realtor or a right-of-way negotiator can prove to be a complex and confusing ordeal for a relocatee. About 6 percent of those who offered final comments indicated that their primary concern was a lack of information and advice on real estate procedures and legal questions. It is just this confusion or resentment that adds strength to anti-highway sentiment in a community and may cripple the development of well-conceived transportation programs. It could be argued, therefore, that some highway funds might be well invested to "defuse" the emotional reactions of property owners who feel that they have been taken advantage of because of their lack of real estate knowledge. One constructive approach might be to prepare a brochure containing a simple description of a typical right-of-way transaction and the process of finding a new home. An actual case history or two, with illustrations, narrating the experiences of "Mr. and Mrs. Smith" might be a suitable approach. The presentation should be aimed at the elderly and at persons of moderate means, for others will probably have no need of this kind of assistance.

Four relocatees in 10 felt that they were not given enough time to "shop around" for new dwellings. When asked what they thought should be done to help other people, which was not done in their own cases, one-third of the relocatees stated that more notice should be given before residents must move.

Not only does the evidence indicate that relocatees would probably not have selected neighborhoods substantially different from their actual relocation sites if they had been given more time, but it also indicates that allowing more time actually leads to other problems. Families living in an area containing some vacant buildings must contend with vandalism. About 11 percent of the relocatees named vandalism as their main concern. The most ready answer to those who feel that they must shop around more is to point out that it would be to their advantage to vacate their houses in the right-of-way at about the same time their neighbors move away.

Problems of the elderly were the primary concern of about 1 relocatee in 8. Relocatees felt that elderly people deserved special financial assistance, that they should be provided with special physical assistance in moving, and that they should be treated more gently. There is evidence to show that relocation may have serious emotional effects on elderly people because of their displacement from familiar surroundings.

The primary concern expressed by about 1 relocatee in 5 was money. Some relocatees were disappointed because they felt that insufficient consideration was given to improvements they had made on older houses. Others felt that they should have received some compensation for the inconvenience of being required to move.

Other matters of financial concern were higher interest rates for new mortgages and higher taxes at new locations. The advent of the relocation allowance under the Highway Act of 1968 and subsequent legislation should help to alleviate a concern expressed by many: "The home may not be worth too much because of age, but in order to buy another like it you need more money."

Relocatees seemed to be more concerned about moving into the same type of neighborhood than with the prices of replacement housing, provided that they enjoyed adequate incomes. This sentiment was verbalized by a number of relocatees and seems to be borne out by the analysis of moving behavior. It would seem, therefore, a mistake to overemphasize the economic aspects of the relocation experience or to assume that financial allowances will relieve more than a fraction of problems experienced by relocatees.

Some relocatees were opposed to expressway construction, and some were concerned only that an expressway was to traverse their old neighborhoods. About 6 percent of the relocatees who offered final comments indicated that their primary concern was opposition either to expressways in general or to I-90 in particular.

"They're doing what they can do. We need more and better roads." Thus spoke one relocatee who represents the 6 percent who offered comments to the same effect.

CONCLUSIONS

Analysis of moving behavior lends support to the following conclusions:

1. Relocatees tend to select residences as close as possible to their old homes;

2. Relocates tend to select new neighborhoods having a social status equal to or higher than that possessed by their former homes, provided that they are financially able to do so; and

3. With respect to the tendency to maintain or upgrade the social status of their neighborhoods, the behavior of relocates is not substantially different from that of an independent sample of voluntary movers.

Unfavorable attitudes toward the relocation experience attenuate with the passage of time, but the rate of attenuation is inversely proportional to age and length of residence at the pre-relocation address. To a lesser degree, the rate at which unfavorable feelings attenuate is directly proportional to income and to educational attainment.

Strictly financial concerns were not necessarily uppermost in the minds of most interviewees. About one-fifth of the relocates mentioned financial matters as objects of their primary concern. But others were primarily disturbed about a variety of non-economic considerations. Relations with state employees and the special problems of the elderly were among the most commonly mentioned matters. It is concluded that the payment of relocation allowances and rent supplements, although necessary and just, cannot in itself relieve the psychic burdens that must be shouldered by relocates. The elderly relocatee is especially in need of sympathetic treatment, substantive assistance in finding a new home, and sound advice.

Relocates with at least some college education were more likely than others to entertain a favorable opinion toward the selection of the alignment for I-90.

Monthly housing expense was substantially higher for relocates as a result of their having moved. Many relocates had substantial equities in their old homes, and they applied the proceeds from these sales to the state directly toward their new homes.

Structural condition of housing currently occupied by relocates was found to be generally satisfactory. The size of new quarters, in terms of median rooms per dwelling unit, seemed somewhat larger than that of pre-relocation dwellings. A few dwellings were found to be deficient with respect to standards for decent, safe, and sanitary housing.

Changes in tenure were predominately from tenant to owner. More than half of the relocates who had been tenants became owners after relocation. The necessity to relocate seems to have provided an incentive to purchase a home among younger households of adequate means.

Relocation had little effect on employment. Only 5 percent of those interviewed changed jobs because of being relocated. About a third of the relocates reported that their trips to work were longer than they had been prior to relocation.

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USER AND COMMUNITY BENEFITS IN INTERCITY FREEWAY CORRIDOR EVALUATION

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Quantitative measures are proposed for evaluating the impact of new freeways on desired state development patterns and on opportunities for employment and other socioeconomic interactions. Implications of different relative weights for combining these measures with user benefits were investigated and appropriate relations proposed. Combining all benefits into a dollar-equivalent effectiveness allowed computation of an effectiveness-cost ratio useful for establishing corridor priorities. This evaluation methodology is applied to 17 potential freeway corridors in New York State.

•THIS paper presents a methodology of highway corridor evaluation that was found useful in a recent study of potential additions to the New York State freeway system. The study was conducted as part of a coordinated program to develop a statewide highway plan that will include freeways, other expressways, arterials, and perhaps also collectors in both urban and rural areas. The approach taken in the evaluation is generally applicable and may be of interest to analysts faced with similar tasks in other states and to those interested in consistency of evaluation among states.

THE PROBLEM

The problem addressed in a study of rural highway needs is different from that of many other transportation studies. The problem faced is not one of solving a crisis situation, as it often is in urban transportation studies. Primarily because of the far-reaching Interstate program, the present system of expressways and major arterials serving long-distance travel is extensive, direct, and at most times free of congestion. In New York State average operating speeds in rural corridors are typically only slightly lower than the legal speed limit. Planned and committed extensions of the intercity expressway system in the state will increase rural expressway mileage (not including parkways) from 960 miles in 1971 to more than 1,400 miles by 1975. Although it is true that in many rural sections greater highway capacity is required to accommodate increasing travel demand, few rural roads need to be upgraded to expressway standards. Adequate capacity can usually be provided at much lower cost by widening existing roads where needed, constructing grade-separated interchanges at strategic locations, and improving traffic control.

Additions to the freeway system may, however, be justified for other reasons. For example, they may be needed to stimulate economic activity in some areas. Or they may be needed to improve access to recreational areas or cultural activities. In other words, the evaluation of potential freeways cannot depend solely on an analysis of user benefits such as reduction of vehicle operating costs or highway safety. Community benefits should be considered in the evaluation as well.

PURPOSE AND SCOPE OF STUDY

The purpose of the highway corridor evaluation was to identify routes or major sections of routes in the nonurban highway system that could justifiably be upgraded to

freeway standards. No attempt was made to determine whether improvement of any of these routes or sections to less than freeway standards would be a better economic investment. A marginal investment analysis of lesser levels of improvement would be necessary before any route could be finally designated as a possible freeway.

A total of 920 miles of potential additions to the existing and committed intercity freeway system was considered. The 17 corridors evaluated, identified as corridors A through Q, included most routes that the Department of Transportation had seriously considered as potential locations for some type of rural expressway. The locations were selected on the basis of earlier suggestions from several sources: department staff, staff of the former New York State Office of Planning Coordination, regional planning boards, county and local planners, and other responsible agencies and individuals. Because of the broad range of sources, it can be assumed that statewide interests were well represented in the selection of possible expressway locations. Most corridors were analyzed in more than one segment, the length of each segment varying from 4.4 to 76.7 miles.

APPROACH

The corridor evaluation relied heavily on previous analysis and available data. Although the large number of expressway proposals considered in past years by the department had received varying degrees of study (generally on a project-by-project basis), the extent of these proposals was sufficiently large to form, with minor additions, a comprehensive network from which recommended freeway corridors could be drawn.

It was recognized that a highway plan should reflect the broadest range of transportation goals (6). The goals considered in the evaluation of potential freeway corridors were of 2 types: user benefits, which involve the maximum return on public investment in terms of reduced accidents, operating costs, and travel time; and community benefits, which are achieved primarily by promoting desirable development patterns (7) and increasing interaction opportunities, the opportunities of residents of one area to satisfy employment, medical, and similar needs in other areas. Because techniques for considering user benefits and community benefits together are still rudimentary, the evaluation stressed consistency and realistic assumptions rather than rigorous analysis and development of new data.

The basis for evaluation was effectiveness-cost analysis, which emphasizes quantitative measurement of benefit and cost, even where these measures are in units that are incommensurate. Measurement of benefits was carried beyond the traditional measurement of savings in travel time, accidents, and operating cost, in that an attempt was made to establish measures for the impact of potential freeways on area development and interaction opportunities. Other benefits, such as highway-system continuity and facilities for national defense, were assigned a subjective but consistent weighting in the evaluation.

A network analysis for the computation of diversion from one freeway to another would require input data and techniques that are yet to be developed. It is anticipated, however, that system impacts would be relatively minor. The amount of freeway construction funds expected for the next decade limits the extent of the future freeway system. But, even if more funds were available, it is unlikely that many freeways would be added to the system; most of the major corridors among major cities have either existing or committed freeways, and there will be a decreasing return for each additional dollar invested. Thus, with the relatively large spacing anticipated (compared with the average length of trips on such roads), only limited diversion of travel from one freeway to another can be expected.

If it is assumed that the diversion to and from routes in alternative freeway plans is negligible for most alternate plans, route analysis can be used for the evaluation. Previous volume estimates, made independently on a project-by-project basis, were therefore used to derive the volume-related benefits. In cases where system impacts from existing or committed freeways had not been considered in previous volume estimates and were felt to be significant, an adjustment was made.

User benefits (time, accident, and operating-cost savings) were determined in a relatively straightforward manner, with assumed characteristics of the potential free-way and assumed accident rates, operating costs, and travel speeds. Community benefits were determined less directly. Fostering the physical development of the state and increasing interaction opportunities are often the major purposes of freeway and expressway proposals. There are areas in which the state wishes to encourage growth; increasing the access to those areas, it is hoped, will make them more desirable locations for new activity. Measures of these community benefits were therefore related to the increase in accessibility. Community benefits unrelated to accessibility were determined by means of a subjective index.

Construction costs from existing studies were used in the analysis after adjustment of some figures to bring the costs to a common year. It was anticipated that many routes would not require development to full freeway standards at first; therefore, the desirability of staging was considered for each route.

USER BENEFITS

The benefits of reduced travel time, reduced vehicle operating costs, and increased safety must be evaluated in the justification of any freeway. The benefits traditionally considered include savings to the automobile travelers and truckers who would use the new expressway and to the traveler who would continue to use existing highways that would become less congested as a result of the new expressway. The procedure used to calculate savings in time, operating costs, and accidents is similar to that used in urban transportation studies and to the procedure recommended in the AASHO guidelines (1), and will therefore not be repeated here. Only some of the inputs to the analysis of user savings will be discussed.

To estimate savings in travel time, we calculated both free-flow and average daily operating speed for each section of each existing highway and each proposed freeway. Free-flow speed was assumed to equal a route section's average speed limit, which was obtained from statewide highway records. Average operating speed for each section was determined by adjusting free-flow speed to reflect speed reductions during the daily peak travel hours; speed-volume curves in the Highway Capacity Manual (5) were used to make the adjustment.

When possible, estimates of average daily traffic were taken from past studies conducted by the department. If volume estimates had to be developed, they were calculated by using the traffic forecasting procedure followed for the 1970 Interstate cost estimate (2), the same procedure used to prepare many of the previously published estimates of average daily traffic. Predicted volumes were found to be low when compared to urban expressway forecasts, and generally much lower than freeway capacity. Average daily traffic ranged from about 4,000 to 14,000 for 1975 and from about 5,000 to 22,000 for 1990.

The unit cost figures used to convert travel-time benefits into dollar values are consistent with those used in the department's urban transportation studies. Travel time was valued at \$2.50 per vehicle hour. This figure was obtained by adjusting the value suggested by the Federal Highway Administration for cost-of-living increases and an assumed average truck proportion of 10 percent (3).

To quantify the second type of user benefit, reduction in vehicle operating costs, we used operating costs of 4 and 10 cents per mile for automobiles and trucks respectively.

The accident rates used to calculate accident savings were taken from the Traffic Engineering Handbook (4) and were developed for several levels of average daily traffic and roadway type. The unit cost of an accident was set at \$2,920, which reflects wage losses, insurance costs, property-damage costs, and medical expenses. This average cost was estimated as a function of the mix of accidents (personal injuries, fatalities, and property damage) and the probability of occurrence of each accident type.

To perform an economic analysis of each proposed expressway required that an interest rate be specified for discounting future user savings to a present dollar value; a 10 percent interest rate was used in the study. All dollar equivalents of user benefits are assumed to be constant "real" values; they were adjusted to reflect anticipated

future inflation. The Consumer Price Index, which was used to inflate user savings, was assumed to decrease from approximately 5 percent annually in 1970 to 2½ percent annually from 1975 through 1990.

COMMUNITY BENEFITS

Unlike urban freeways, which are often built because user benefits have been found to equal or exceed the total construction and maintenance cost, freeways in rural areas usually cannot be justified solely on the basis of user savings; user savings are likely to be large yet insufficient to cover costs. Identification and quantification of other benefits are essential in determining whether a rural freeway is justified. The part of the New York freeway corridor evaluation that is really different from past transportation studies is the explicit account of the goals of promoting desired development patterns and increasing interaction opportunities. These goals may be broadly classified as community benefits of the transportation system.

Although it is clear that improvements to transportation affect community goals, the extent of this effect in relation to other development prerequisites is not clear. Therefore, the approach taken in the study was not to attempt measuring actual benefits but to develop measures indicating the relative impact of alternative expressway proposals on community goals without assuming any specific magnitude of these impacts. It was believed that, if community benefits can be determined or assumed for one corridor, these measures permit the computation of corresponding community benefits for all other corridors.

The basic concept to which these goals were related is that of accessibility. Defined as "ease of communication," accessibility rises as the number of potential destinations or attractions increases, and it decreases as various impedances, such as distance or travel time, increase; when a new road is added, travel time shortens, increasing the accessibility of the zones directly affected by the road. Accessibility is also an important factor in defining an effective market for commercial, industrial, cultural, and other activities, and thus it is important in industrial and other economic-activity location. Represented by population or other attractions, markets are weighted according to their distance or travel time from the zone in which the activity is, or may be, located.

The accessibility measure used in the corridor evaluation is expressed as

$$A_i = \sum_j P_j / T_{ij}^k$$

where

- A_i = accessibility of zone i ,
- P_j = population (or other attraction) of zone j ,
- T_{ij} = travel time between zones i and j , and
- k = distance exponent.

The accessibility measure was calculated by the use of 633 zones within the state (zone boundaries coincide with one or more minor civil divisions) and 67 larger zones representing adjacent state areas. Accessibility was summed over all zones within the state to determine total, or statewide, accessibility.

To demonstrate the change in accessibility that results from the addition of an express highway and to provide a guide for selecting an appropriate distance exponent, k , we analyzed the existing highway system with and without the addition of I-88 between Binghamton and Albany. As shown in Figure 1, the increase in accessibility is generally greatest for zones adjacent to the new facility. $k = 1$ was selected after a comparison was made of the extent and distribution of accessibility changes resulting from different k -values with what was intuitively felt to be the influence area of the expressway.

Specific measures related to accessibility were developed for the 2 goals; the measures are called index A and index B. Index A was used to measure the degree to which desired development patterns would be fostered. Index B was used to measure the degree to which interaction opportunities would be increased.

Desired Development Patterns

The change in relative accessibility was considered the best measure of the effect that a freeway might have on the degree to which economic development is directed from one zone to another. Relative accessibility is defined as

$$RA_i = A_i / A$$

where A is the sum of the accessibility of all zones in the state.

The change in relative accessibility identifies zones affected negatively as well as those affected positively. For example, the addition of I-88 to the existing system changed the relative accessibility of Oneonta (located on the freeway) and Buffalo (approximately 200 miles from Oneonta), as shown below:

Zone	RA_i	Change (percent)
Oneonta	+0.00004455	+3.00
Buffalo	-0.00000268	-0.03

The relative accessibility of Oneonta increased by 3 percent, while that of Buffalo dropped slightly. These changes are small, but to Oneonta's economy they may be significant.

New York State's development plan suggests that, for the social, economic, and physical benefit of the state, growth in some zones should be emphasized. The plan identifies other zones in which development should be retarded because an increase in activity would create environmental pressures in conflict with the plan. In corridor evaluation, therefore, the change in relative accessibility should be weighted by a factor reflecting the extent to which the change in projected growth varied from the change in growth judged desirable in the state development plan. The summation for all zones within the influence area of a proposed facility of this weight multiplied by the change in relative accessibility (index A) was used as the measure of achievement of the goal of promoting the state development plan:

$$\text{Index A} = \sum_i w_i \times RA_i$$

where

w_i = weight given to zone i, and

RA_i = change in relative accessibility of zone i.

Development weights ranging from -3.5 to 7.5 were developed in cooperation with the Office of Planning Coordination. Positive values indicate zones where growth is favored. When relative accessibility significantly increased in zones with negative weights, these zones were identified and appropriately considered in the further evaluation of route impacts.

The relation between the Department of Transportation and the Office of Planning Coordination is analogous to the relation between transportation planning and comprehensive regional planning agencies in metropolitan areas. Unlike most other corridor planning, however, the New York freeway evaluation attempted to quantify goal achievement rather than to rely on the traditional intuitive approach.

Interaction Opportunities

The addition of a freeway may provide benefits other than user benefits and the promotion of desired development. A new freeway may also improve the access of residents in one area to job opportunities, emergency medical facilities, cultural activities, and other attractions available in other areas. The ability of residents of one area to interact with other areas to take advantage of such opportunities is a true benefit, even if infrequently used.

Although specific interaction opportunities can be located, projected, and used in the analysis, it was assumed for this study that attractions such as retail, medical, and cultural facilities are distributed in the same way as population. It was assumed, therefore, that a zone's change in accessibility, as defined above, is an appropriate measure of the zone's change in interaction opportunities.

Inasmuch as this benefit accrues to every resident of the zone, the zone population times the change in accessibility summed over all zones affected (index B) was used as a measure of how much a new freeway would increase interaction opportunities.

$$\text{Index B} = \sum_i P_i \times \Delta A_i$$

where

P_i = population of zone i , and

ΔA_i = change in accessibility of zone i .

Other Benefits

Certain attractions, such as recreation areas and colleges, are not distributed in the same way as population. Improvement in access to such facilities and provision for other needs such as national defense and system continuity cannot be measured by index B. These benefits were identified where possible and evaluated on a subjective but consistent basis. Unavoidable adverse impacts on the environment that were identified were included as negative benefits. An index based on a 0 to 10 scale was assigned to each corridor.

COSTS

Most of the potential freeways analyzed had been the subject of previous department studies, and their costs had been estimated in project information reports, route-location studies, or the 1970 Interstate cost estimate. All construction costs were updated to 1970 dollars by means of the Highway Bid Price Index. It was assumed that inflation would increase 1970 costs by a factor of 2 by 1990; this increase reflects a 7 percent annual price increase through 1972 with a leveling off to 3 percent annually after 1974. Most of the cost increase would be due to growing labor costs, although rising material and equipment costs would also contribute. All costs were inflated to year of construction—1975 for stage 1 of the plan and 1985 for stage 2—before present worths were calculated. Maintenance costs were assumed to be \$5,000 per mile for routine snow removal, painting, grass mowing, and rubbish removal. Reconstruction of the pavement was assumed to be required every 20 years, at a cost of \$100,000 per lane-mile.

Staged construction, 2 lanes at a time, was considered because low volumes were forecast in some corridors. However, including staged construction in the analysis had a negligible effect on results because roads with very low volumes were not chosen as desirable investments.

User Benefit-Cost

As a first step in evaluating each proposed route, the ratio of user savings to costs, the benefit-cost ratio, was calculated with construction assumed during the 1975-80 period. This ratio served as the bench mark for evaluating the dollar value of development and other benefits of freeway construction. The results of the calculation are given in Table 1 under the column heading "Standard Variables."

At first glance, these benefit-cost ratios appear to be extremely low. They range from somewhat more than 0.5 for corridors A, L, M, and O to as low as 0.17 for corridor Q. (A wider range of benefit-cost ratios was observed on individual route segments.) These results must, however, be considered in light of the historical development of the state's intercity freeways and of recent trends in the construction industry.

New York's existing freeway system, which was constructed during the past 2 decades, has preempted the corridors with the highest volumes and the highest congestion levels. The corridors considered in this study, on the other hand, are generally characterized by relatively low traffic volumes and fairly high traffic speed. Unlike earlier facilities, many of the recent proposals would provide small unit benefits to a small traffic volume. Consequently, the aggregate of benefits is low. Another important consideration affecting the benefit-cost ratios is the rapidly increasing cost of construction. The estimated costs used here are considerably higher than estimates used in earlier studies. The value of benefits has also been inflated, but at a lower rate.

It was considered necessary to isolate the impact of changes in input data and thus verify the reasonableness of the results. A sensitivity analysis was performed by varying 1 variable at a time while all others remained constant. Variable changes were as follows:

<u>Variable</u>	<u>Standard</u>	<u>Changed</u>
Interest rate, percent	10	6
Time value, \$/vehicle-hour	2.50	1.75
Accident value, \$/accident	2,920	5,840
Expressway threshold volume, vehicles/day	6,000	9,000
Expressway volume increase, percent	—	30
1990 Nonexpressway speed reduction, percent	—	30
Inflation rate		
Costs, percent	3.0	6
Benefits, percent	2.5	5

The results of this analysis are given in the remaining columns of Table 1.

The sensitivity analysis indicated that changes in several factors may materially affect the benefit-cost ratio. The most sensitive variable was the assumed average operating speed on the existing road. Changing the interest rate also had a significant effect; using a rate of 6 percent rather than 10 percent increased the benefit-cost for all routes by approximately 65 percent. The unit value of time was important, and the rate of inflation was also found to be of consequence. In contrast, changing the estimated expressway volume, the unit value of accidents, and the expressway threshold volume (i. e., the volume at which 4 lanes are required) resulted in only minor changes in the benefit-cost ratios. The most important input variables were carefully reexamined to ensure that the best available information was used in establishing their values.

Community Benefit-Cost

The community benefit-cost ratio was not used alone as a measure but was combined with the user benefit-cost ratio into an effectiveness-cost ratio, as described in the next section. The community benefit-cost ratios for each route are shown as part of the effectiveness-cost ratios in Figure 2.

CORRIDOR EVALUATION

The measures of user and community goal achievement were integrated into a total benefits, or effectiveness, measure for each corridor, and the resulting effectiveness-cost ratio of each potential freeway was used in arriving at a final corridor recommendation.

Community benefits cannot be assigned dollar values and, thus, cannot be added directly to user benefits. Furthermore, there is no objective way of establishing a unit value for community benefits. Consequently, because their weighting must necessarily be based on subjective judgment, the total value of these benefits is open to discussion.

What were believed to be reasonable unit values for the selected community-benefit measures (index A, index B, and the index for other benefits) were established by

Figure 1. Accessibility change with addition of I-88.

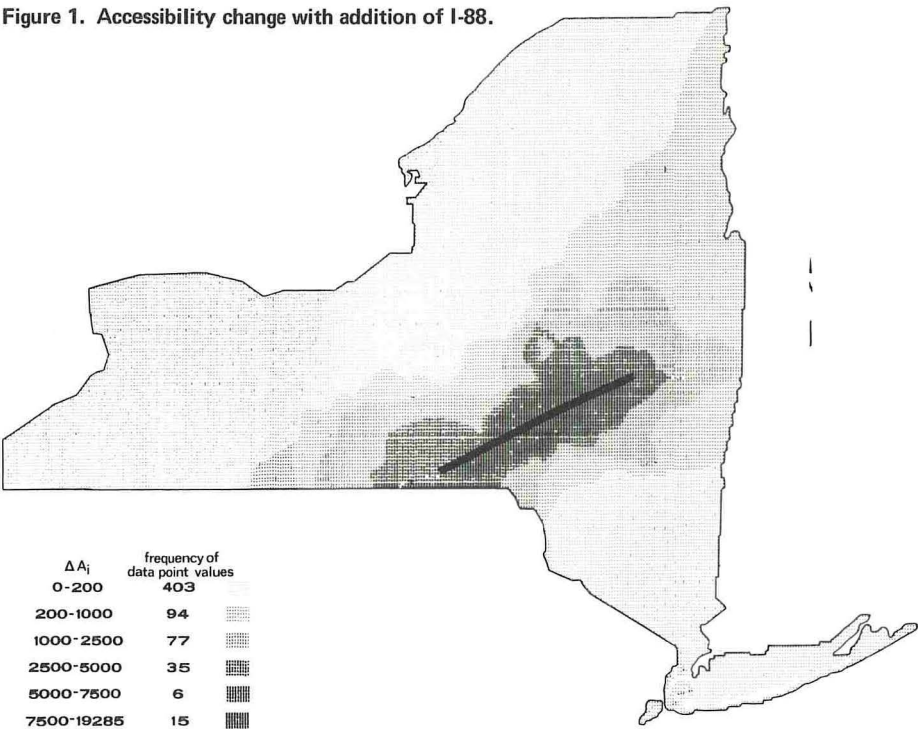


Figure 2. Corridor ratings.

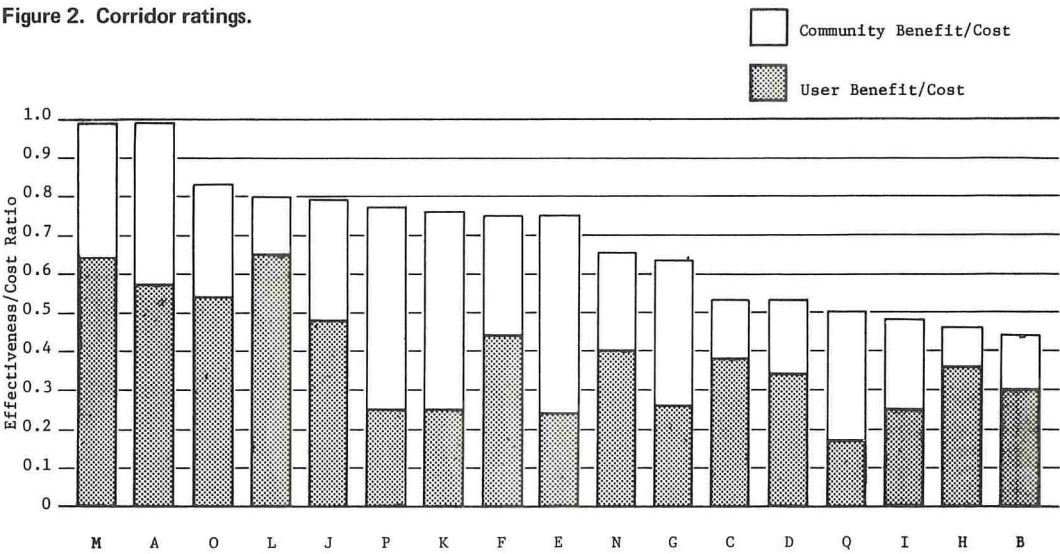


Table 1. User benefit-cost ratios with standard and changed variables.

Corridor	Section	Benefit-Cost Ratio With Standard Variables	Benefit-Cost Ratio With Variables Changed for Sensitivity Analysis						Inflation Rate
			Interest Rate of 6 Percent	Time Value	Accident Value	Expressway Threshold Volume	Expressway Volume Increased	1990 Nonexpressway Speed Reduced	
A	1	0.27	0.47	0.21	0.34	0.32	0.31	0.60	0.36
	2	1.30	2.24	0.97	1.44	1.30	1.51	2.82	1.71
	3	0.85	1.43	0.64	0.96	0.85	0.96	1.82	1.11
	Total	0.57	0.97	0.43	0.66	0.63	0.65	1.23	0.75
B	1	0.10	0.17	0.08	0.10	0.10	0.12	0.22	0.13
	2	0.36	0.55	0.29	0.44	0.43	0.39	0.89	0.43
	3	0.36	0.58	0.29	0.45	0.39	0.42	0.83	0.46
	Total	0.30	0.47	0.23	0.36	0.32	0.33	0.70	0.37
C	1	0.56	0.92	0.46	0.74	0.56	0.64	1.22	0.71
	2	0.18	0.31	0.14	0.23	0.20	0.21	0.60	0.24
	3	0.39	0.60	0.30	0.44	0.47	0.42	0.88	0.47
	4	0.32	0.46	0.26	0.35	0.37	0.32	0.66	0.37
	Total	0.38	0.59	0.30	0.46	0.42	0.41	0.87	0.46
D	1	0.12	0.17	0.08	0.11	0.13	0.12	0.37	0.14
	2	0.32	0.51	0.26	0.38	0.39	0.35	0.75	0.39
	3	0.85	1.40	0.66	1.04	0.85	0.97	1.83	1.09
	Total	0.34	0.51	0.26	0.39	0.37	0.36	0.80	0.40
E	Total	0.24	0.39	0.20	0.36	0.26	0.29	0.61	0.31
F	1	0.31	0.52	0.23	0.33	0.40	0.35	0.81	0.41
	2	0.59	0.99	0.46	0.66	0.59	0.68	1.19	0.77
	Total	0.44	0.74	0.34	0.49	0.50	0.50	0.99	0.57
G	Total	0.26	0.40	0.21	0.33	0.31	0.30	0.63	0.32
H	1	0.49	0.81	0.39	0.61	0.49	0.56	1.13	0.63
	2	0.26	0.43	0.21	0.36	0.26	0.30	0.76	0.33
	3	0.25	0.41	0.20	0.28	0.29	0.29	0.63	0.32
	Total	0.36	0.61	0.29	0.45	0.38	0.42	0.89	0.47
I	Total	0.25	0.44	0.21	0.33	0.26	0.30	0.58	0.33
J	1	0.55	0.84	0.40	0.57	0.61	0.63	1.69	0.68
	2	0.37	0.55	0.29	0.45	0.44	0.42	1.12	0.45
	3	0.51	0.75	0.39	0.59	0.59	0.58	1.53	0.61
	Total	0.48	0.72	0.36	0.54	0.55	0.54	1.46	0.58
K	1	0.30	0.52	0.23	0.36	0.34	0.35	0.67	0.40
	2	0.19	0.30	0.15	0.23	0.23	0.21	0.45	0.23
	Total	0.25	0.42	0.20	0.31	0.29	0.29	0.57	0.32
L	Total	0.65	1.07	0.50	0.71	0.70	0.74	1.31	0.84
M	1	0.77	1.24	0.58	0.92	0.77	0.91	1.83	0.98
	2	0.57	0.92	0.42	0.58	0.57	0.68	1.49	0.73
	Total	0.64	1.04	0.48	0.70	0.64	0.76	1.62	0.82
N	Total	0.40	0.64	0.32	0.52	0.40	0.47	1.04	0.51
O	1	0.71	1.14	0.55	0.84	0.71	0.82	1.58	0.90
	2	0.41	0.66	0.33	0.49	0.49	0.48	0.86	0.52
	Total	0.54	0.87	0.43	0.64	0.60	0.63	1.18	0.69
P	1	0.32	0.55	0.24	0.35	0.38	0.37	0.88	0.42
	2	0.15	0.21	0.11	0.17	0.16	0.15	0.50	0.17
	Total	0.25	0.39	0.19	0.27	0.28	0.26	0.71	0.31
Q	1	0.30	0.51	0.25	0.37	0.32	0.36	0.62	0.39
	2	0.15	0.27	0.12	0.19	0.20	0.18	0.34	0.20
	Total	0.17	0.31	0.13	0.21	0.22	0.20	0.39	0.23

Table 2. Effectiveness-cost ratios with varying weights of community benefits.

Corridor	60-20-20 Weight ^a			40-40-20 Weight ^a			User Benefit-Cost Ratio
	50 ^b	75 ^b	100 ^b	50 ^b	75 ^b	100 ^b	
M	0.88	0.99	1.11	0.88	1.00	1.12	0.64
A	0.86	0.99	1.14	0.85	0.99	1.14	0.57
O	0.73	0.83	0.92	0.73	0.83	0.92	0.54
L	0.75	0.80	0.85	0.75	0.80	0.85	0.65
J	0.69	0.79	0.90	0.68	0.79	0.89	0.48
P	0.60	0.77	0.95	0.57	0.73	0.89	0.25
K	0.59	0.76	0.92	0.63	0.82	1.01	0.25
F	0.65	0.75	0.86	0.64	0.74	0.83	0.44
E	0.58	0.75	0.92	0.55	0.70	0.85	0.24
N	0.57	0.65	0.73	0.57	0.65	0.73	0.40
G	0.51	0.63	0.75	0.50	0.62	0.74	0.26
C	0.48	0.53	0.59	0.48	0.53	0.57	0.38
D	0.47	0.53	0.60	0.46	0.52	0.58	0.34
Q	0.40	0.50	0.61	0.37	0.47	0.57	0.17
I	0.41	0.48	0.56	0.41	0.49	0.56	0.25
H	0.42	0.46	0.49	0.42	0.45	0.48	0.36
B	0.39	0.44	0.48	0.39	0.44	0.49	0.30

^aWeights given to (a) promoting the state development plan, (b) increasing interaction opportunities, and (c) other benefits, such as national defense and system continuity.

^bCommunity benefits as a percentage of user benefits, with corridor A as the base.

Figure 3. User benefit-cost ratios for different construction years.

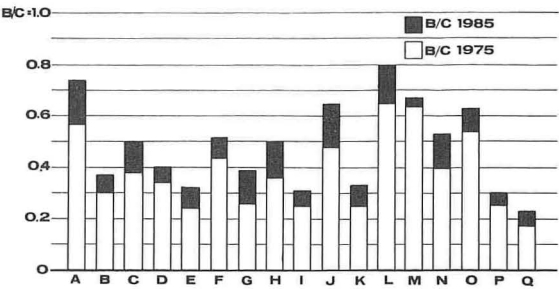


Table 3. Corridor evaluation summary.

Corridor	Factor ^a	User Benefits			Community Benefits			Total Benefits or Effectiveness	Cost (millions)		Effectiveness and Cost Ratio	User Benefit and Cost Ratio
		Reduced Travel Time	Reduced Operating Costs	Increased Safety	Promotion of State Development Plan	Increased Interaction Opportunities	Other Benefits		Construction	Maintenance		
A	1	36	3	6	70	41	6	194	180	15	0.99	0.57
	2	90	3	18	50	17	17					
	3	0.46	0.02	0.09	0.26	0.09	0.09					
B	1	16	6	4	19	14	3	85	176	20	0.44	0.30
	2	41	6	12	13	6	8					
	3	0.21	0.03	0.06	0.07	0.03	0.04					
C	1	40	16	11	59	26	3	207	350	38	0.53	0.38
	2	99	16	31	42	11	8					
	3	0.26	0.04	0.08	0.11	0.03	0.02					
D	1	26	6	5	44	18	4	134	226	26	0.53	0.34
	2	64	6	14	31	8	11					
	3	0.26	0.02	0.06	0.13	0.03	0.04					
E	1	5	-1	3	43	15	2	63	74	9	0.75	0.24
	2	12	-1	9	30	6	6					
	3	0.14	-0.01	0.11	0.36	0.08	0.07					
F	1	23	10	3	55	23	2	129	156	14	0.75	0.44
	2	57	10	3	39	10	6					
	3	0.33	0.06	0.05	0.23	0.06	0.03					
G	1	8	0	2	34	17	3	68	96	12	0.63	0.26
	2	21	0	7	24	7	8					
	3	0.19	0.00	0.07	0.22	0.07	0.08					
H	1	56	16	18	51	20	3	261	523	50	0.46	0.36
	2	140	16	52	36	8	8					
	3	0.24	0.03	0.09	0.06	0.01	0.02					
I	1	6	2	3	19	11	2	49	95	8	0.48	0.25
	2	16	2	8	13	5	6					
	3	0.16	0.02	0.08	0.13	0.05	0.05					
J	1	24	3	3	36	19	5	119	131	20	0.79	0.48
	2	59	3	9	26	8	14					
	3	0.40	0.02	0.06	0.17	0.05	0.09					
K	1	14	1	3	69	68	4	132	161	14	0.76	0.25
	2	34	1	9	49	28	11					
	3	0.19	0.01	0.05	0.28	0.16	0.06					
L	1	22	9	2	15	8	1	89	100	11	0.80	0.65
	2	56	9	7	11	3	3					
	3	0.50	0.09	0.06	0.10	0.03	0.03					
M	1	26	5	3	26	17	6	119	107	13	0.99	0.64
	2	65	5	7	18	7	17					
	3	0.54	0.04	0.06	0.15	0.06	0.14					
N	1	9	0	3	14	8	2	50	69	9	0.65	0.40
	2	22	0	9	10	3	5					
	3	0.29	0.00	0.11	0.13	0.04	0.07					
O	1	25	10	6	48	27	1	138	149	18	0.83	0.54
	2	63	10	17	34	11	3					
	3	0.38	0.06	0.10	0.20	0.07	0.02					
P	1	16	4	2	106	41	3	148	174	18	0.77	0.25
	2	39	4	4	75	17	8					
	3	0.21	0.02	0.02	0.39	0.09	0.04					
Q	1	9	0	2	49	16	5	85	157	11	0.50	0.17
	2	22	0	6	35	7	14					
	3	0.13	0.00	0.04	0.21	0.04	0.08					

^a1 = units of benefits; 2 = total dollar equivalent of benefits in millions; and 3 = percentage of cost covered by benefits.

comparing the results of applying several different weights to the community benefits as a percentage of user benefits and different weights to one type of community benefit versus another. Unit values for the 2 community benefits, promoting desired development patterns and increasing interaction opportunities, were computed for each set of weights by using index A, index B, and other benefit ratings of 1 base corridor. These unit values were then consistently applied to all the other corridors to obtain a dollar equivalent for community benefits. Adding user and community benefits and dividing by estimated freeway costs gave effectiveness-cost ratios (Table 2). A sensitivity analysis indicated that other corridors could have been used as the base without substantially changing the corridor ranking.

Different proportioning among the community goals did not materially affect the ratios. Selection of the appropriate weight of community benefits versus user benefits proved to be far more difficult. There are few available research findings that can be applied in making this selection; therefore, the implications of different proportions were examined more carefully.

It is immediately apparent that, when community benefits are equal to 50 percent of user benefits for base corridor A, no routes would be selected. At 75 percent, 2 routes have an effectiveness-cost ratio of nearly one or greater. This implies an expressway program of \$230 million. Forty-one percent of this cost, or \$94.3 million, would be justified on the basis of hoped-for community benefits. On the other hand, the assumption that community benefits are equal to 100 percent of user benefits implies a \$664 million program, 56 percent of which, or \$370 million, would be justified on the basis of community benefits. Furthermore, some of the routes in the larger program require that community benefits justify more than 74 percent of the cost. Although it is generally acknowledged that community benefits contribute to the justification of intercity freeways, it is difficult to justify such a major proportion of their cost without far more concrete research supporting the relation between accessibility-related measures and hoped-for community benefits. This problem, and the more manageable size of the program implied by weighting community benefits at 75 percent of user benefits (for the base corridor), led to the selection of that ratio for further analysis.

With community benefits weighted at 75 percent of user benefits, the distribution of 60 percent to the goal of promoting the state development plan, 20 percent to increasing interaction opportunities, and 20 percent to other benefits was selected. The reason for the dominant weight given to promotion of the state development plan is that this plan already reflects a number of important social, environmental, and economic state goals. Figure 2 shows the corridor ranking with these weights according to the effectiveness-cost ratio obtained by combining the separate measures of user and community benefits for each corridor. Community benefits were found to vary greatly among corridors, both in relation to one another and as a percentage of user benefits.

Should other weights be considered more appropriate, only minor adjustments would be needed to reflect them in the final plan. It should be remembered, however, that any selection of weights implies a definite set of projects in the final plan and that the selection of any project would logically require the selection of all projects having a higher effectiveness-cost ratio.

Table 3 gives in more detail the benefits and cost of each corridor in terms of the level of goal achievement, the estimated benefit value per unit of goal achievement, and the estimated dollar equivalent and amount of each dollar invested that is covered by the achievement of each goal. The figures shown are based on a weighting of community benefits at 75 percent of user benefits for corridor A. Measure weights are as follows:

User benefits

Reduced travel time: millions of hours, \$2.50/hour
Reduced operating cost: millions of dollars, 1.00
Increased safety: thousands of accidents, \$2,920/accident

Community benefits

Promotion of development plan: index A, millions, 0.71
Increased interaction opportunities: index B, millions, 0.41
Other benefits: 0 to 10 scale, millions, 2.77

Before a final corridor recommendation could be made, it was necessary to analyze each section of routes having a high effectiveness-cost ratio. In some cases, where construction of the entire route is not required for system continuity, individual sections may be justified even if the entire route is not. A user benefit-cost analysis was performed for each section with both 1975 and 1985 as possible construction dates. The resulting benefit-cost ratios, shown in Figure 3, were found to increase as construction was delayed, primarily because of increased travel volumes.

On the basis of total route evaluation and benefit-cost evaluation of each route section, only part of 1 corridor was recommended for construction between 1975 and 1980, and only 2 additional corridors were found to justify freeway construction between 1980 and 1990. For each of these, further detailed analysis will be undertaken to determine whether full freeway improvement is justified. This analysis will compare the incremental benefits over improvements to less than full freeway standards with incremental costs.

CONCLUSION

It should be emphasized here that the justification of any or all of the recommended routes has not been proved, for the dollar value of community benefits has no empirical basis. If, however, the proportion of the total freeway program justified by community benefits is accepted as reasonable, corridor ranking and selection are objective and consistent.

The evaluation of possible new freeways in New York State (capacity increases on existing freeways were not considered) led to very limited recommendations for possible additions to the existing or committed freeway system. In less densely populated states, similar results may be expected. The small number of recommended corridors does not, however, mean that improvements to the intercity highway system should be discontinued; it indicates, rather, that there should be a shift in emphasis toward the arterial system. Intercity and rural travel is served by both the freeway and the arterial systems, and this combined system must be improved to serve the increasing travel demand safely and efficiently. Once the freeway system is completed, a major effort will be needed to upgrade the system of principal and minor arterials. This improvement, although not justified to full freeway standards, may require standards superior to those currently used for the arterial system and may include continuous improvement to expressway (as opposed to freeway) standards on some facilities and construction of limited-access bypasses for small communities, lane additions or widenings, grade-separation structures, and traffic-control improvements on others. In many areas, such improvements will permit travel at nearly expressway speeds at a fraction of expressway cost.

The methodology described in this paper was developed under severe limitations on time and manpower resources. However, it is felt that the evaluation procedure will give a logically based and reasonable ranking of alternatives that is of considerable value in deciding on the magnitude and nature of a freeway program.

The measures used for indicating the relative impact of alternate freeways on community goals need to be further examined for general validity. Furthermore, the appropriate weight to be given to community-benefit measures must be explored through detailed economic analysis of selected corridors. (A preliminary comparison with ongoing analyses of this type was indeed possible for 2 of the corridors and showed acceptable results.) A number of such comparisons will be needed to ascertain generally applicable weights and, consequently, to reliably predict community benefits of freeways.

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PLANNING CRITERIA FOR OFF-STREET SERVICE AREAS

E. M. Whitlock and J. G. Schoon, Wilbur Smith and Associates

This paper describes essential characteristics of certain existing truck freight service areas and operational aspects of the facilities based on field study. Sampled study projects include office and retail-oriented developments in New York, Connecticut, Pennsylvania, and Texas. Evaluations were made of the relations of design and operational aspects, number and frequency of truck arrivals, durations of stay, vehicle types, and generation rates based on number of service vehicles and floor area of major land uses. Additional research using a mathematical estimate of arrival rates from the known data (Poisson distribution) supports the application of this technique for predicting potential use of an off-street truck service area.

• THE optimum design of truck freight receiving facilities in congested city areas is of utmost concern in minimizing costs to carriers, the public, and freight recipients. In addition to cost, inconvenience, noise, air pollution, and aesthetics must be considered in truck freight service area planning and design.

This paper describes typical characteristics of existing service facilities physically separated from, but related to, city streets via service tunnels and off-street areas where unloading and loading operations are carried out. Characteristics of land use areas, operating techniques, numbers and types of trucks, and space requirements and a comparison of theoretical design methods are presented.

PHYSICAL CONFIGURATIONS

Functional design of truck terminal facilities is generally dictated by location and size of the development to be served, by access available from adjoining streets, and frequently by underground obstructions and soil conditions. The concern of this paper is essentially with off-street surface and underground truck service facilities served by a tunnel or ramp access.

Four basic service area types are shown in Figure 1. The 4 selected configurations are as follows:

1. A single access, 2-way service area with truck bays at right angles to the roadway with a mechanical assist (turntable) to facilitate reversing direction of vehicles (this arrangement would only normally be used in instances where horizontal dimensions are below those necessary for vehicles to maneuver unassisted);
2. A configuration similar to the first arrangement but without a turntable and with an extended area where turn-around maneuvers may be conducted without mechanical assistance;
3. A 2-way roadway with loading-unloading bays at right angles to facilitate entering and exiting from either end of the facility; and
4. A 1-way system with truck bays arranged in a sawtooth pattern (this configuration provides service vehicles loading-unloading capacity with a minimum width of service tunnel).

Loading areas may be included along sides of roadways in addition to designated truck bays, depending on the types of goods and vehicles being handled and the available turning radii. Also, combinations of the configurations given above may be provided for specialized conditions. Internally, goods are generally transferred to smaller carts, elevators, vehicles, or microsystems for transshipment to final destinations within the buildings served.

OPERATIONAL CONSIDERATIONS

Depending on size and composition of the off-street vehicle service areas, methods of operation vary considerably. The following factors affect operations: location of service area, land uses served, functional design of service area, number of loading-unloading berths, frequency of truck arrivals and departures, ownership of access street, times of service vehicle loading-unloading, labor policies, and management controls dictated by building owners.

It is desirable to maintain published hours of operation, which, in theory, should be during evening hours when local streets have capacity to serve access needs. This is difficult, however, in view of service vehicle (delivery) requirements of the building during the day and desire to minimize evening work.

Of utmost importance is maintenance of surveillance in the service area during all hours of operation. Some service tunnel operations require truck drivers to sign a log when entering and leaving, and others perform this function with a full-time dispatcher. Closed-circuit television is also utilized in some service areas to ensure security. Where sight distances are restricted, traffic control devices (signs, signals, pavement markings, and channelization) are used to establish rights-of-way, control ingress-egress, set speed limits, and facilitate safe operations.

Frequently, after the construction of extensive redevelopment over existing streets, truck service tunnels may remain as dedicated city streets, in which case all necessary traffic signing and law enforcement must be carried out in accordance with city ordinances. Access in these cases implies use of a public street, and individual owners are, therefore, sometimes required to fence and control access to loading-unloading bays.

LAND USES ASSOCIATED WITH EXTENSIVE TRUCK-FREIGHT SERVICE FACILITIES

The most extensive specialized freight-handling facilities, apart from manufacturing and freight transfer terminals, are those required for retail, commercial, and office use.

Types of goods delivered depend on the land use served and vary from large equipment deliveries by large trucks to frequent small-package deliveries during the day. Also, regular truck movements for garbage disposal and other daily service functions affect design and operation. In some cases, particularly where the garbage is characterized by early decomposition, refrigeration or other special storage facilities may be required.

CHARACTERISTICS OF SURVEYED LOCATIONS

Features of the several locations investigated for this paper are given in Table 1. Each of these developments comprises office or retail establishments or both. Gross floor areas of the buildings studied range from approximately 250,000 sq ft for Roosevelt Field Shopping Center to approximately 5 million sq ft for Rockefeller Center.

Configurations of the loading-unloading areas investigated consist of most features previously described. An interesting exception is the access system to the Time-Life Building service area; it consists of 2 elevators onto which trucks are driven before they are either lowered or raised between the service and street levels. At Rockefeller Center, a single access leads to a large rectangular area around which the truck bays are located. The service area to Chapel Square includes both a sawtooth configuration and bays at 90 deg to the access road. The number of bays associated with these service

Figure 1. Schematic arrangement of typical truck freight-handling configurations.

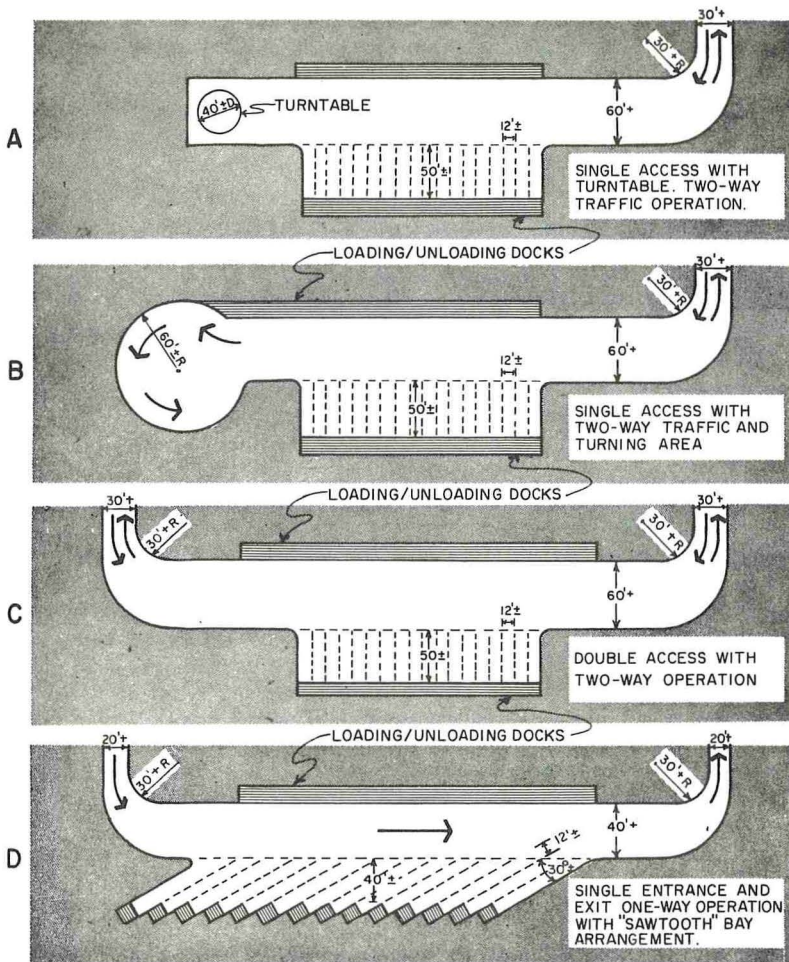


Table 1. Freight service characteristics at selected locations.

Location	Location Number	Type of Land Use	Net Floor Area of Building (sq ft)	Unloading Area Configuration	Loading-Unloading Bays
Center city locations					
Time-Life Building, New York	1	Office, retail	1,500,000	Elevator entry and exit and turntable	7
Rockefeller Center, New York	2	Office, retail	5,000,000	Single access, 2-way with central maneuvering area and peripheral bay locations	30
Chapel Square, New Haven	3	Retail, office	900,000	Single, 2-way access with 1-way internal circulation sawtooth and 90-deg bays	12
Penn Center Plaza, Philadelphia	4	Office, retail	1,750,000	Dead-end roadway with adjoining 90-deg unloading bays	7
Midtown Plaza, Rochester	5	Office, retail	1,200,000	Single 2-way access with truck bays at 90-deg to underground bays	20
Republic Bank Building, Dallas	6	Office, retail	1,300,000	Street level operations	7
Suburban locations					
Westchester County Shopping Center, New York	7	Retail	260,000	Surface level loading-unloading bays	3
Valley Stream Shopping Center, Long Island	8	Retail	270,000	Surface level loading-unloading bays	4
Roosevelt Field Shopping Center, Long Island	9	Retail	250,000	Surface level loading-unloading bays	5

areas varies from 3 at the Westchester County Shopping Center to 30 in Rockefeller Center.

Deliveries are frequently made to the buildings by vehicles parking, legally and illegally, at the curbs on surface streets. Unless very stringent regulations and enforcement are implemented, this is an unavoidable, undesirable feature of building service. Adequate design capacity, signing, and arranging off-street service areas in good proximity to local streets can improve this situation and enhance nearby traffic operations.

TRUCK SERVICE PROVISION AND UTILIZATION DATA

The daily number of trucks arriving at the facilities observed varied from 34 at Westchester County Shopping Center to 440 at Rockefeller Center (Table 2). These data apply to typical weekdays, and considerable fluctuations to higher levels can be expected during other times of the year, such as at Christmas. Friday tends to be a busy day for truck deliveries to retail establishments because of anticipated weekend demands.

Daily truck arrival rates per 1,000 sq ft of floor area were observed to vary from 0.088 to 0.195. The former occurred at Rockefeller Center and the latter at Chapel Square, New Haven. Reasons for the wide difference appear to be that Rockefeller Center is predominantly an office type of complex and Chapel Square is oriented to retail activities requiring considerably greater truck movements because of merchandising requirements. It is further noted that because of the ease of access-egress to the service area at Chapel Square more trucks utilized this area. At Rockefeller Center, many deliveries were made from vehicles that were parked or double parked at the curb and not recorded in the subject survey.

Generally, urban store customers demand more home delivery of purchased merchandise than do suburban customers. Historically, an average of 11 percent of urban purchases and 3 percent of suburban purchases are delivered to the residence of the purchaser. Because of this, less stock is normally kept in the urban store and deliveries of purchased goods are made directly from a central warehouse.

Furthermore, a significant characteristic for comparing store operations at urban versus suburban locations is duration of loading dock operations. In the urban store, the receiving bay pattern is more dispersed during receiving hours and, therefore, fewer trucks per hour are likely for a given floor area. For these reasons, the planned hours of dock operation from 7:00 a.m. to 7:00 p.m. compare with 8:00 a.m. to 4:00 p.m. at suburban locations. Vehicular loading-unloading activities by type of vehicle are given in Table 3 for a suburban shopping center store. Influence of local supplier trucks on this store is most significant.

Definitions of truck service are as follows:

1. Shuttle. Vehicle serving goods movements from store to store or from warehouse to store.
2. Local supplier. Vehicle serving goods movements to the store by outside supplier.
3. Long-haul. Vehicle serving goods movements oriented to the store from outside the city.
4. Customer service. Vehicle serving goods movements such as parcel pickup or delivery by U.S. mail, United Parcel Service, or Railway Express Agency.

The approximate floor areas served by a single truck bay vary from approximately 50,000 sq ft at Chapel Square to 250,000 sq ft at Penn Center Plaza. Differences reflect variations in goods requirements between retail and office activities and the ease of access and capacity of the service areas.

Of critical importance in the design of facilities is the average utilization likely to be experienced by each truck bay to enable a direct relation to be extrapolated between arriving vehicles and the number of bays to be provided. The daily truck turnover per bay is approximately 25 vehicles at Penn Center Plaza and approximately 7 vehicles at Roosevelt Field Shopping Center. Other observed turnovers ranged between these values.

Of the trucks visiting the Time-Life Building, approximately 80 percent were pickup trucks or station wagons, 19 percent were medium-sized vans, and only 0.5 percent were semi-trailers (Table 4). Of the daily loading-unloading truck activity at this location, 64 percent took place at curbside and 36 percent took place in the off-street truck service area.

DEMANDS FOR BERTHS

Needs for individual loading-unloading dock spaces are affected by the character of tenant activities in buildings being served, methods of service area operation, size of building complex, and arrival-departure patterns of the service vehicles. For small retail-commercial establishments, the unit loading dock requirements are generally greater than for larger complexes because of the frequency of vehicle arrivals and departures. These needs range from about 1 space for each 10,000 gross sq ft of floor area to 1 space for each 25,000 sq ft for office buildings and mixed retail uses.

For the large office-commercial complexes, field studies support a theoretical demand for about 1.4 dock spaces for each 100,000 gross sq ft of floor area. Most building codes are responsive to this situation.

Many large department store chains have greater control over deliveries than do office buildings because of central warehousing operations. In large metropolitan areas, for instance, a major retail chain may serve as many as 10 stores from 1 central distribution point. With this approach, management can exercise control of times of truck arrivals and departures and thereby gain more efficient use of fewer dock spaces.

Typical dwell times or load-unload durations for trucks utilizing off-street loading areas by vehicle type at suburban shopping centers around New York are as follows:

Vehicle Type	Duration of Stay (min)		
	Minimum	Maximum	Average
Panel or pickup	5	20	12.5
2-axle, 6-tire and over	5	35	15.5
Semi-trailer	5	15	10.5

At the Time-Life Building, 47 percent of truck durations at the service area were less than 20 min and only 13 percent remained for more than 1 hour. Overall, the average service time was 26 min; for semi-trailers, the average duration was about 1 hour (Table 5).

TRUCK ARRIVAL PATTERNS

Truck arrivals observed throughout the day indicate that at Rockefeller Center the maximum arrival rate occurs between approximately 10:00 a.m. and 2:00 p.m. (Fig. 2). In some cases truck deliveries and collections were permitted during evening hours; however, this is generally infrequent and was only noted in isolated cases. Also apparent was the fact that truck arrival patterns appear to be essentially similar on surveyed weekdays—Monday, Tuesday, and Thursday. Prior experience at retail-oriented service areas indicates that more activity occurs on Friday than on other days, however.

Truck arrivals may indicate less pronounced peaking characteristics than those shown in Figure 2. The rate of arrivals between 8:00 a.m. and 4:00 p.m. at the Time-Life Building did not vary significantly, as shown in Figure 3. The difference between arrivals at curb spaces on adjacent streets and arrivals at dock spaces is also of interest, and activity at curb spaces is a significant proportion of the total.

COMPARISON BETWEEN ACTUAL AND THEORETICAL ARRIVAL CHARACTERISTICS

Several factors may affect truck arrival patterns at loading and unloading areas, thus rendering adequate representation of actual events by theoretical distributions only partly effective. Particularly in city center locations, interruptions to specific arrival

Table 2. Truck service at selected locations.

Location	Observed Daily Truck Arrivals	Daily Truck Arrivals per 1,000 Sq Ft	Approximate Floor Area Served by 1 Truck Bay (sq ft)	Avg Daily Truck Turnover ^a
1	225 ^b	0.150	215,000	12
2	440	0.088	167,000	15
3	175	0.195	75,000	15
4	180	0.120	250,000	25
5	167	0.162	60,000	8
6	183	0.140	186,000	26
7	35	0.135	87,000	12
8	36	0.135	68,000	9
9	34	0.135	50,000	7

^aNumber of trucks per bay per day. ^bIncludes truck deliveries made at street level.

Table 3. Type of service by trucks loading and unloading daily at suburban shopping center store from 8:00 a.m. to 4:00 p.m.

Vehicle Type	Shuttle	Local Supplier	Long- Haul	Cus- tomer Service	Total
Light panel or pickup	—	1	—	3	4
2-axle, 6-tire and larger	2	22	3	—	27
Trailer truck	—	3	1	—	4
Total	2	26	4	3	35

Note: Data were collected at loading dock of suburban department store with 260,000 sq ft of gross floor area on March 15, 1967.

Table 4. Loading activity at Time-Life Building from 7:00 a.m. to 7:00 p.m.

Vehicle Type	Curb	Docks	Total	Percent
Light truck	110	69	179	79.5
30-ft van	35	10	45	19.0
Semi-trailer	—	1	1	5
Total	145	80	225	100.0
Percent	64	36	100.0	

Note: Data were collected on November 4, 1966.

Table 5. Loading or unloading durations at Time-Life Building from 7:00 a.m. to 7:00 p.m.

Vehicle Type	0-10 Min	11-20 Min	21-30 Min	31-40 Min	41-50 Min	51-60 Min	Over 60 Min	Total	Avg
Light truck	44	39	33	22	10	7	24	179	27
30-ft van	9	14	11	5	2	—	4	45	25
Semi-trailer	—	—	—	—	—	—	1	1	60+
Total	53	53	44	27	12	7	29	225	26
Percent	23.6	23.6	19.5	12.0	5.3	3.1	12.9	100.0	

Note: Data were collected November 4, 1966.

patterns may be caused by nearby construction activities, proximity of traffic signals, or presence of a toll or other factors tending to impose a regulated arrival pattern on the traffic stream.

Probably the most extensively used and the most practical theoretical arrival distribution technique is the Poisson distribution. Data were obtained for truck arrivals in several of the surveys completed for a variety of arrival intervals varying from 2 to 30 min. Mean arrival rates and sample variances were computed, and comparisons were made between observed data and theoretical distributions.

Table 6 gives a comparison of actual and theoretical distributions for truck arrival intervals of 4 min for a 2-hour period at Rockefeller Center. Notation in the table is defined as follows:

- x = number of arrivals during 4-min interval,
- f = frequency of observed arrival intervals,
- F = frequency of theoretical arrival intervals, and
- n = total intervals.

The theoretical arrivals are based on a Poisson distribution where the probability P of arrivals x exceeding a given level c for an average arrival rate during interval m is expressed as

$$P(x \geq c) = 1 - \sum_{x=0}^c (m^x/x!) \cdot e^{-m}$$

A χ^2 test for goodness of fit was made for these data to support the hypothesis that the theoretical distribution approximated the actual distribution at the 5 percent level of significance. Actual and theoretical data were plotted (Fig. 4) and, based on cumulative frequency of arrival periods, coincide reasonably well.

Knowledge of truck arrival distributions is essential for properly planning entrance and exit facilities, reservoir space, and internal freight-handling facilities and for assessing likely traffic impacts on the adjacent street network. The distribution of arrivals during a given percentage of intervals can be used to estimate the risk of exceeding an acceptable level of accommodation, and designs can be made accordingly.

Computations

The following equations, relating to data given in Table 6 and shown in Figure 4, illustrate the computation of the sample mean, variation, and χ^2 goodness of fit test.

$$\text{Mean arrival rate, } m = \sum fx / \sum f = 51/30 = 1.7 \text{ trucks/4-min interval}$$

$$\text{Variance, } s^2 = \left\{ \sum fx^2 - [(\sum fx)^2/n] \right\} / (n - 1) = 1.39$$

$$\text{Computed value of } \chi^2 = (\sum f^2/F) - n = 0.02$$

$$\text{Degrees of freedom} = 3 - 2 = 1$$

$$\text{Tabulated value } \chi^2_{0.05, 1} = 3.84$$

Essentially, if the computed value $\chi^2 = (\sum f^2/F) - n$ is less than the tabulated value of χ^2 for a given level of significance (in this case 5 percent) and degrees of freedom (in this case $3 - 2 = 1$), then the theoretical distribution provides an acceptable approximation of the actual distribution for the mean arrival rate considered.

Because the tabulated χ^2 value of 3.84 is greater than the computed χ^2 value of 0.02, the observed data may be assumed to provide an acceptable fit to the Poisson distribution at the 5 percent level of significance. The Poisson distribution is applicable to arrival patterns in the instance shown but may not be suitable for all arrival interval lengths or all periods of arrival.

Figure 2. Observed pattern of freight-truck arrivals at Rockefeller Center.

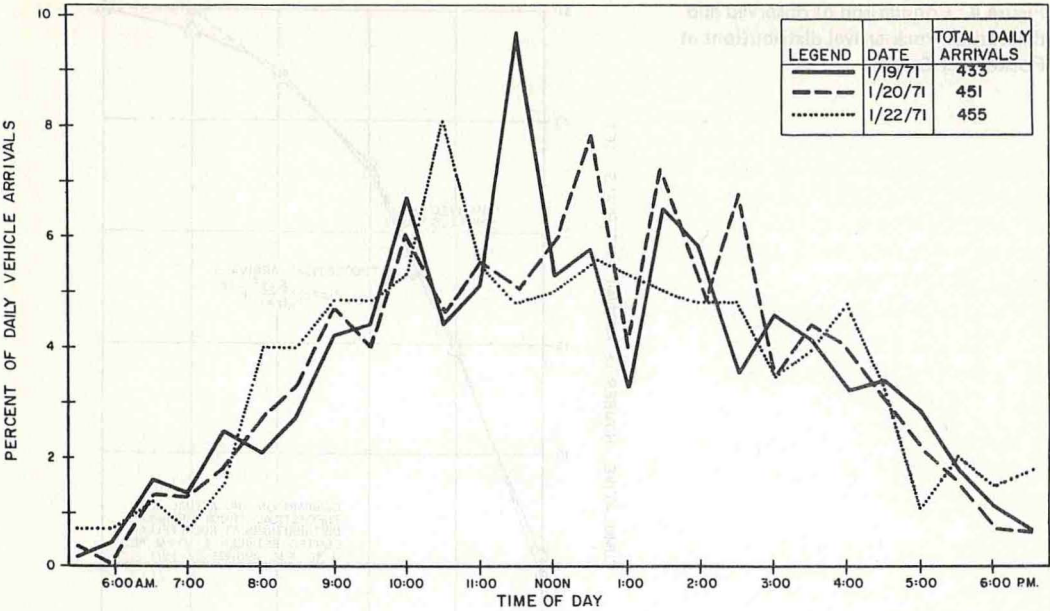


Figure 3. Freight-delivery arrivals to curb and dock delivery areas at Time-Life Building.

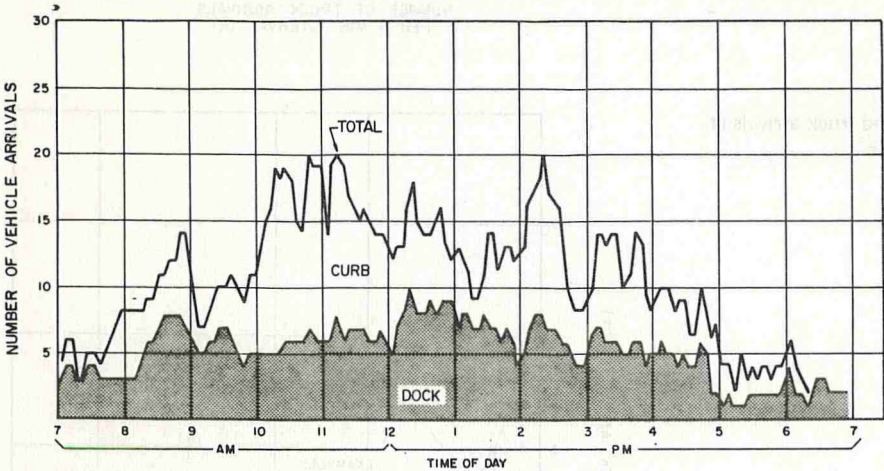


Table 6. Actual and theoretical truck-arrival distributions at Rockefeller Center.

x	f		F		f ² /F ^a
	Number ^a	Cumulative	Number ^a	Cumulative	
0	4	4	5.49	5.49	15.21
1	11	15	9.30	14.79	
2	8	23	7.92	22.71	
3	4	27	4.50	27.21	6.72
4	3	30	1.89	29.10	
>4	0	0	0.90	30.00	
n	30		30.00		30.02

Note: Data were collected August 17, 1971, between 2:30 and 4:30 p.m.

^aGrouping of individual frequencies to provide values of at least 5 and computations of f²/F are necessary for completion of χ^2 goodness of fit test.

Figure 4. Comparison of observed and theoretical truck-arrival distributions at Rockefeller Center.

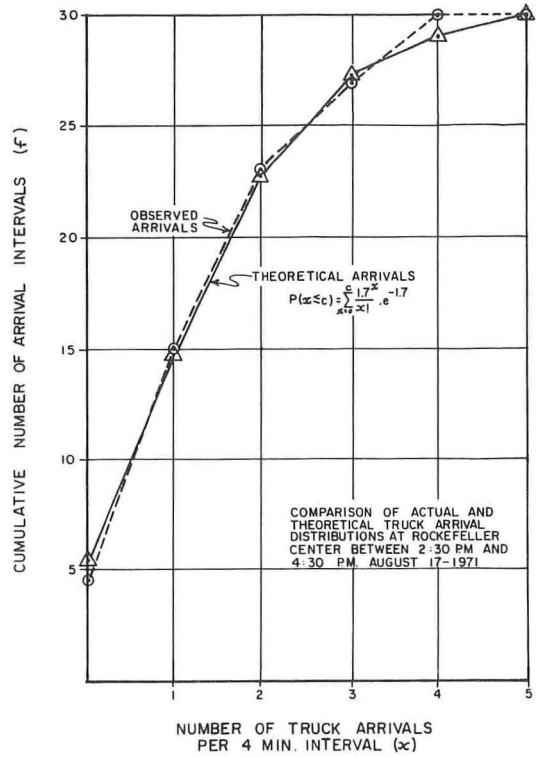
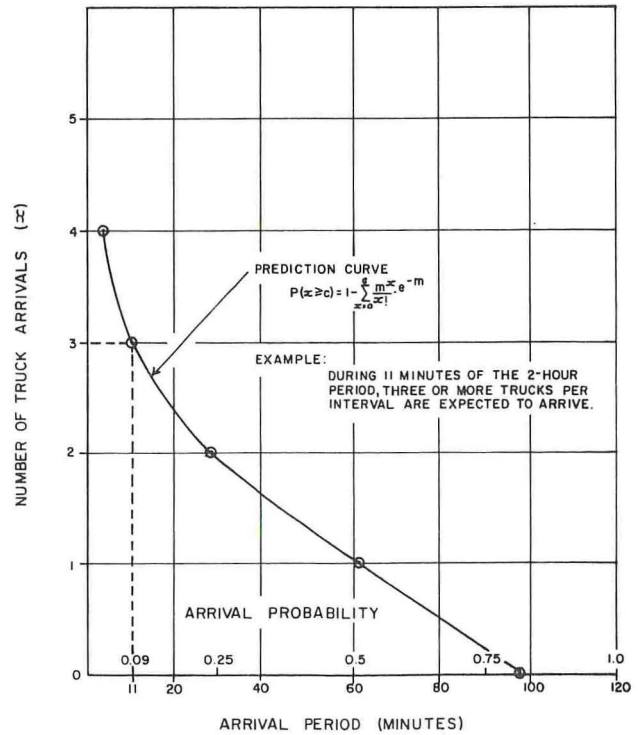


Figure 5. Predicted truck arrivals at Rockefeller Center.



Prediction Curve for Truck Arrivals

After verification was made of an acceptable fit between observed arrival distributions and a Poisson arrival distribution, a curve indicating the number of trucks expected to arrive during given portions of the total arrival period was prepared (Fig. 5). This serves as a planning aid only and should be constructed to suit the mean arrival rate and number of truck arrivals anticipated. This curve makes it possible to determine the likely period during which, say, c or more trucks will arrive and thus provides an indication of design adequacy and probability of design capacity being exceeded.

Example

An example of the use of the curve is the determination of the least period of time during which 3 or more trucks will likely arrive. By selecting the value of 3 trucks on the graph and reading to the curve, one can see that at least 3 trucks per interval will likely arrive during 11 min of the 2-hour period considered. This also means that the probability of 3 or more trucks arriving per interval during the 2-hour period is 0.09, thus indicating the degree to which a design of reservoir space, ingress and egress space, and use of signal systems would be adequate.

PROPOSED PLANNING PROCEDURE

Based on the data presented, it is possible to summarize a preliminary design and planning procedure for off-street service areas as follows:

1. Determine floor areas and likely composition of the building considered;
2. Assess the number of anticipated truck bays and daily arrivals based on typical ratios given in Tables 1 through 5 with due regard to building code requirements (considerable judgment and investigation of special conditions is necessary at this stage, and the tabulated ratios should be only a guide);
3. Determine from observations of facilities in similar locations and environments the pattern of truck arrivals, based on the total number expected per day; and
4. Construct a prediction curve similar to that shown in Figure 5 for the average arrival rate, and provide a design adequate for items affected by truck arrival patterns (the arrival pattern curve may not necessarily approximate a Poisson distribution pattern, as determined by a χ^2 test, but can be constructed empirically, if necessary, to suit the conditions most likely to result based upon the inputs mentioned above).

CONCLUSIONS

From the foregoing observations, the following conclusions appear to be characteristic of truck freight facilities in large cities.

1. A number of functional configurations are possible to provide adequate truck vehicular access-egress for off-street services areas at large building complexes.
2. The need to encourage use of off-street service facilities is strongly demonstrated by the fact that more than 60 percent of daily deliveries and collections are made from curbside parking and illegal double parking, even with off-street loading areas available.
3. Demands for loading-unloading bays are greater on a unit basis for smaller developments than for larger developments, ranging from 1 space per 10,000 sq ft of gross office floor area for relatively small buildings to 1.4 spaces per 100,000 sq ft of gross floor area for larger complexes.
4. Turnover rates at off-street service facilities have been observed to be as many as 25 trucks per bay per day.
5. Duration of stay at a loading dock ranges from approximately 5 min for small vehicles to more than 1 hour for larger semi-trailer trucks at office building locations, the average dwell time being 26 min. Shorter durations are noted at major retail facilities, the average being approximately 15 min/vehicle.
6. These observed characteristics of actual arrival and departure patterns of trucks frequenting off-street service areas can be used to develop theoretical mathematical

curves utilizing the Poisson distribution technique. The curves aid in predicting frequency of arrivals when various empirical factors are used. In this paper a recreation of truck arrivals at the Rockefeller Center service area, using Poisson curves and a mean arrival rate of 4-min intervals, produces reliable projections within a 5 percent level of significance.

Emphasis should be placed on proper design, regulation, and enforcement of off-street truck service areas in future central city and congested suburban locations. Values to be gained from provision of these facilities include higher levels of safety to motorists and pedestrians, less street congestion during peak traffic hours, more efficient transfer of goods to major land uses, and better regulation of loading-unloading operations.

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ALLOCATION OF RESOURCES FOR CONSTRUCTION OF TRI-STATE REGIONAL HIGHWAYS

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The purpose of this analysis is to develop alternative proposals for the geographic allocation of freeway construction funds. These allocations can be used as guidelines for the development of alternative regional highway networks. The development of such networks is, however, not considered in this paper. The objective is to emphasize the policy level allocation decision. Furthermore, the development of such a network should not be construed as being a final solution to the network planning problem but rather as a step in the problem solving process. The analysis indicates that the reallocation proposals will provide significant benefit to highway users in terms of reduced per-mile travel costs and increased service. The changes would also lead to a reduction in community impacts because of the reduction in highway construction in the most densely developed portions of the region. Further study must be undertaken to consider the redistributive and equity effects of each of the possible alternatives as well as the original plan.

•A MAJOR policy issue of regional planning is the geographical and functional allocation of limited funds to obtain the greatest benefit for the community. This report describes an approach to the area-wide allocation of capital funds required for construction of the 1985 interim plan for limited-access highways in the Tri-State region (7). The report has 4 sections covering regional objectives for highway travel, highway travel description model, allocation of highway resources, and a comparison of alternative resource allocations.

REGIONAL OBJECTIVES FOR HIGHWAY TRAVEL

The objectives of the regional transportation system must be considered within the framework of overall regional objectives wherein transportation is viewed as a service system. For the purposes of this study, the objectives of the highway investment program have been narrowly construed to be the minimization of per-mile highway user costs subject to the available level of capital investment funds. Prior work has indicated that, although the inclusion of representative community impact costs is important to the selection of an appropriate total investment level, they do not significantly affect the allocation of a predetermined budget.

The overall objective of this study is to determine the allocation of capital resources that will minimize daily time and accident costs, subject to the availability of a fixed capital investment budget. This can be expressed mathematically as follows:

*When this work was performed, Mr. Koppelman was with the Tri-State Regional Planning Commission.

Minimize

$$\sum_{i=1}^N \{ [\$6.00 TC_i + \$2.50 TP_i + \$1,470 EXPA_i + (\$930 + \$320) ARTA_i] / VMT_i \} \quad (1)$$

Subject to

$$\sum_{i=1}^N CCOST_i \leq \text{available budget} \quad (2)$$

where

TC = commercial vehicle time,
 TP = passenger vehicle time,
 EXPA = expressway accidents,
 ARTA = arterial and local street accidents,
 VMT = vehicle-miles of travel,
 CCOST = expressway construction cost,
 N = number of subregional areas, and
 i = the individual areas.

Highway user costs have been interpreted to include only time and accident costs. At the general level of analysis being considered, vehicle operating costs are not significantly affected by changes in the allocation of highway capital investment funds and can therefore be ignored.

Time costs are particularly significant in highway travel. Every day more than 10 million man-hours are spent in motor vehicles in the Tri-State region. This travel time is a major element in the total transportation costs incurred in the process of accomplishing other objectives. For the purpose of this study, the value of commercial time—based on driver salaries, fringe benefits, and depreciation—is estimated to be \$6.00/vehicle-hour. The value of passenger car travel time is estimated to be \$2.50/vehicle-hour based on regional per capita income and average vehicle occupancy rates (3).

Accidents also cause a major portion of the costs of motor vehicle travel. Approximately 1,600 reportable accidents (those resulting in personal injury or damage exceeding \$100) take place every day in the Tri-State region. Per accident costs in the region have been estimated as averaging \$1,470 on expressways and \$930 on other roads. An additional cost of \$320 is assignable to reported accidents on arterials and local streets to account for the frequent occurrence of low-cost unreported accidents on these facilities.

The capital cost of new expressways varies among the subregional areas. These costs have been found to be related to the density of activity and development in each area (1). The estimating equation used in this study is based on population density, spacing between interchanges, and average number of driving lanes (2).

The following analysis and conclusions are based on this formulation of objectives. Separate analyses have indicated that the allocation results are not highly sensitive to minor variations in the values used.

HIGHWAY TRAVEL DESCRIPTION MODEL

To determine the allocation of funds available for highway construction that will minimize highway user costs (Eq. 1) requires that highway travel, system performance, and user costs be described under various assumptions of capital resource allocation. A model capable of providing such a description has been developed for use in the Tri-State region (3). The model is based on demand theory supported by observations of regular and repetitive travel behavior in the region. Specific equations were obtained through use of multiple regression statistical techniques. The model has the following general characteristics:

1. Vehicle-miles of travel can be predicted as a function of vehicle trip ends—origins or destinations—and the available roadway supply,
2. Distribution of vehicle-miles of travel among different classes of facilities can be predicted as a function of the relative supply of different facility types, and
3. Quantitative measures of average performance for each facility type can be estimated from the expected loading of each class of facility.

Projections are made independently for 83 analysis areas (Fig. 1) ranging in size from about 10 square miles in the high-density core of the region to more than 200 square miles in low-density areas on the outer edge of the region.

The expected number of motor vehicle trips in each subregional area is estimated from projections of population, household size, household income, and automobile ownership. [For the purpose of this discussion, the number of expected vehicle trips is considered to be fixed; that is, motor vehicle trip generation is independent of the quality of highway or public transportation service. Additional work must be done to develop a travel demand index that is responsive to changes in the level of service provided. At present this is accomplished by incorporating the accessibility characteristics provided by the proposed highway system into the development of land use projections (5) and therefore also into vehicle trip projections.]

The model provides information on the performance of the highway system in each analysis area in the region and also summarizes the data at the county, state, and regional level. The output has been designed to provide the information required to evaluate the objective function specified in Eq. 1. (Output also includes a variety of system performance measures and estimates of household relocations and land area used.) The operation of the model is shown in Figure 2. The effect of changes in expressway supply on travel parameters is shown in Figure 3. An increase in the supply of expressways in any area leads to an increase in the proportion of total travel that takes place on the faster, safer expressways (Fig. 3a) and thereby results in overall reductions in both travel time (Fig. 3c) and accidents (Fig. 3d). Another effect of an increase in overall highway supply in any area is to reduce average volume per lane on all route types (Fig. 3b), resulting in additional reductions in travel time and accidents. These benefits are subject to diminishing returns; that is, each additional increment of expressway supply yields a smaller reduction in travel time and accidents.

These savings can be reduced to a common index of benefit expressed in dollar terms on an annual basis through the objective function specified earlier (Eq. 1). A comparison between savings and investment may be standardized by computing the estimated savings per year for each thousand dollars of additional investment as shown in Figure 4. The annual savings for each additional unit of investment in a given area depend on the density of development and the level of expressway supply in that area. The negative slope of each curve indicates the diminishing benefits that can be expected from each additional investment as service levels increase in the zone. The upward shift in the curves in areas of higher density (left to right in Fig. 4) indicates that the increased benefits due to relief of higher levels of congestion outweigh the effect of increased construction costs in areas of higher density. However, as one might expect, in extremely high-density areas the construction, right-of-way, and relocation costs increase so rapidly as to outweigh the increase in travel benefits. This occurs in the Tri-State region at densities between 30,000 and 40,000 vehicle trip ends per square mile. It is our expectation that the density at which this transition point occurs will vary from region to region.

ALLOCATION OF HIGHWAY RESOURCES

The distribution of construction funds among subregional areas will influence the overall level of travel time and accident costs. The greatest savings will accrue to the region as a whole when funds are distributed such that the marginal annual savings per \$1,000 additional investment is equalized among all areas as shown in Figure 5.

The resulting expressway supply will vary from very low in the rural and exurban areas, increase in suburban areas, reach a maximum at the fringe of the urban core, and drop rapidly in the center where the costs of highways are too great to justify their construction and where transportation service must be provided by alternative means. The authors believe this "doughnut effect" exists in other large urban areas.

Figure 1. Analysis areas of Tri-State region.

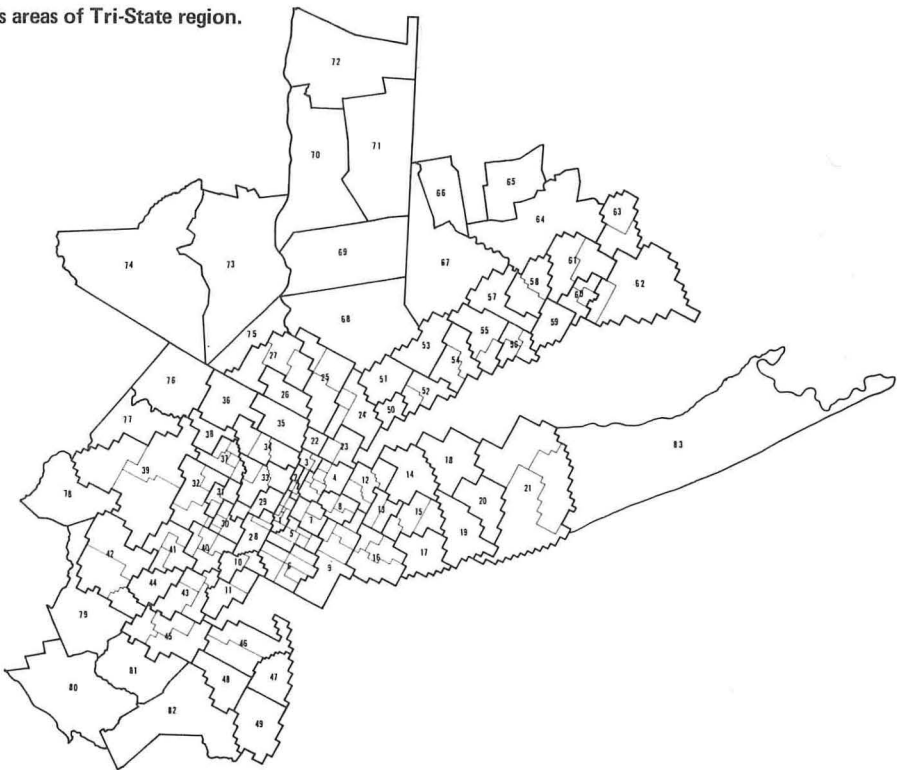


Figure 2. Highway travel description model.

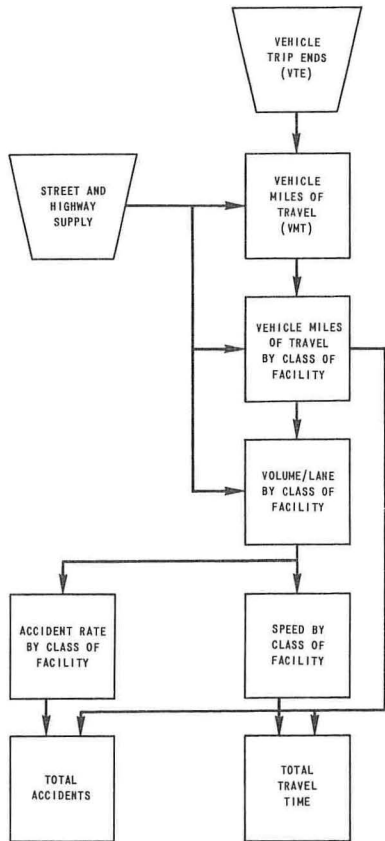
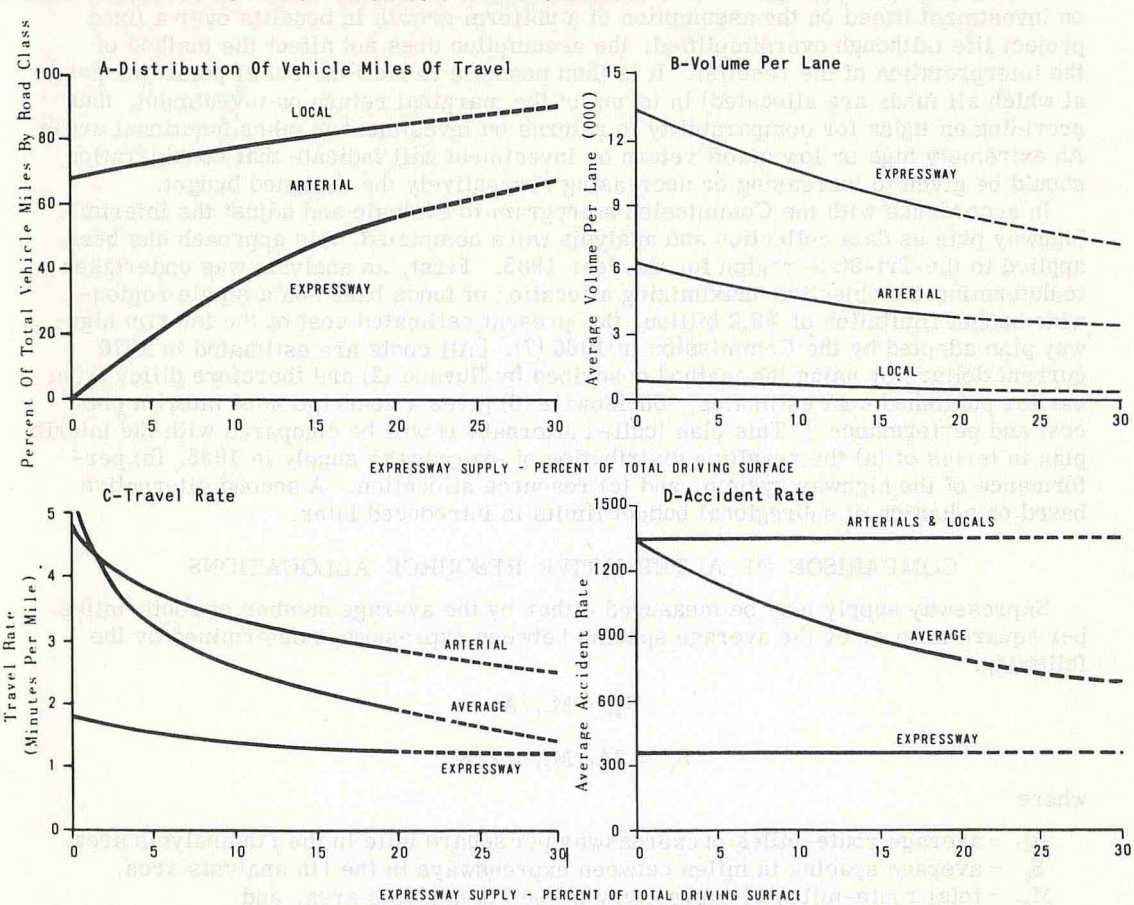
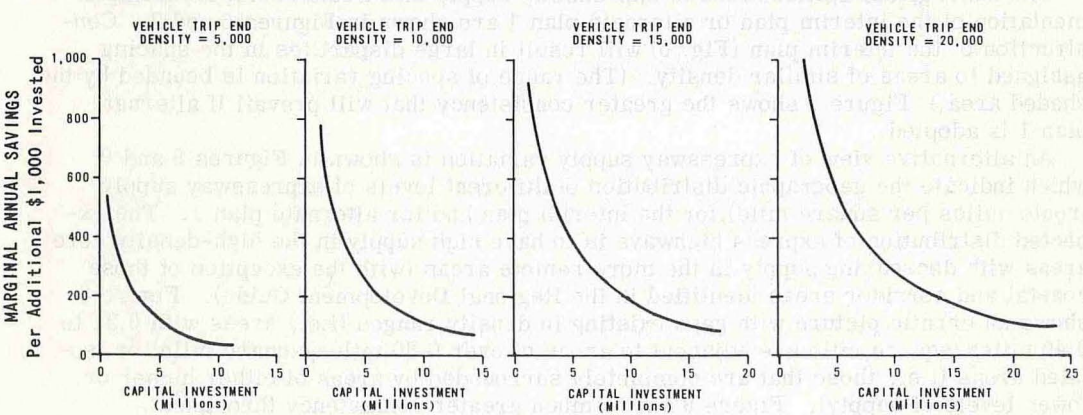


Figure 3. Effect of change in expressway supply on travel parameters.



NOTE: Solid lines indicate range of data (0-20% of road surface being expressways) ; dashed lines are extrapolated

Figure 4. Marginal savings in user costs at different levels of investment in areas of differing density.



The savings per year per \$1,000 invested may be converted to a measure of return on investment based on the assumption of a uniform growth in benefits over a fixed project life (although oversimplified, the assumption does not affect the method of the interpretation of the results). It is then possible to view the cutoff point (the point at which all funds are allocated) in terms of the marginal return on investment, thus providing an index for comparability to returns on investment in other functional areas. An extremely high or low cutoff return on investment will indicate that consideration should be given to increasing or decreasing respectively the assigned budget.

In accordance with the Commission's program to evaluate and adjust the interim highway plan as data collection and analysis were completed, this approach has been applied to the Tri-State region for the year 1985. First, an analysis was undertaken to determine the objective-maximizing allocation of funds based on a single region-wide budget limitation of \$8.2 billion, the present estimated cost of the interim highway plan adopted by the Commission in 1966 (7). [All costs are estimated in 1970 current dollars by using the method described by Huvane (2) and therefore differ from earlier published cost estimates. Shelkowitz (6) gives a description of interim plan cost and performance.] This plan (called alternate 1) will be compared with the interim plan in terms of (a) the resulting distribution of expressway supply in 1985, (b) performance of the highway system, and (c) resource allocation. A second alternative based on adoption of subregional budget limits is introduced later.

COMPARISON OF ALTERNATIVE RESOURCE ALLOCATIONS

Expressway supply may be measured either by the average number of route-miles per square mile or by the average spacing between expressways determined by the following:

$$R_{e1} = M_{e1}/A_1$$

$$S_{e1} = 2A_1/M_{e1} = 2/R_{e1}$$

where

- R_{e1} = average route-miles of expressway per square mile in the i th analysis area,
- S_{e1} = average spacing in miles between expressways in the i th analysis area,
- M_{e1} = total route-miles of expressway in the i th analysis area, and
- A_1 = size of the i th analysis area in square miles.

In general, it is expected that the objectives of equity and efficiency will be best served by an allocation of similar levels of expressway supply to areas with similar levels of travel demand.

The subregional distributions of expressway supply that would result from implementation of the interim plan or alternate plan 1 are shown in Figures 6 and 7. Construction of the interim plan (Fig. 6) will result in large disparities in the spacing assigned to areas of similar density. (The range of spacing variation is bounded by the shaded area.) Figure 7 shows the greater consistency that will prevail if alternate plan 1 is adopted.

An alternative view of expressway supply variation is shown in Figures 8 and 9, which indicate the geographic distribution of different levels of expressway supply (route-miles per square mile) for the interim plan and for alternate plan 1. The expected distribution of express highways is to have high supply in the high-density core areas with decreasing supply in the more remote areas (with the exception of those coastal and corridor areas identified in the Regional Development Guide). Figure 8 shows an erratic picture with gaps existing in density ranges (i.e., areas with 0.21 to 0.40 miles/square mile are adjacent to areas of over 0.80 miles/square mile) or isolated areas (i.e., those that are completely surrounded by areas of either higher or lower levels of supply). Figure 9 shows much greater consistency throughout.

System Performance

The second comparison is with respect to the performance of the different plans, where performance is evaluated with respect to total vehicle-miles of travel served,

Figure 5. Optimal allocation of resources to subregional areas.

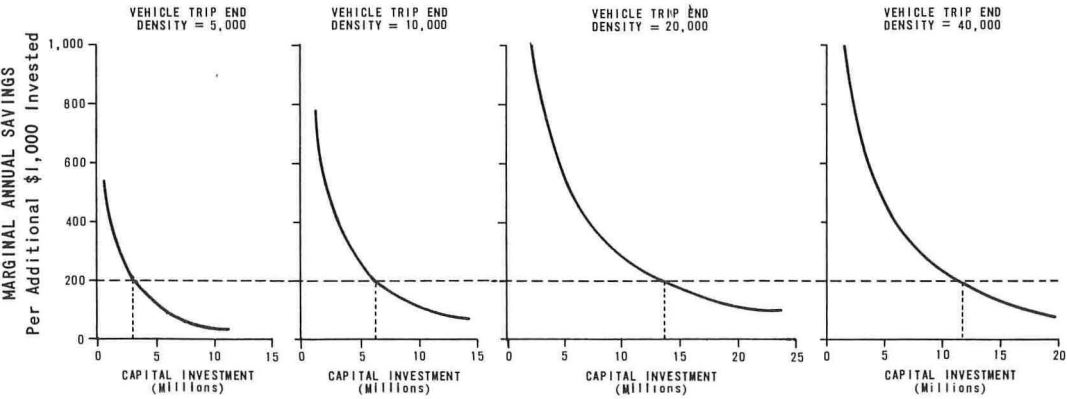


Figure 6. Expressway spacing versus vehicle trip end density with interim plan.

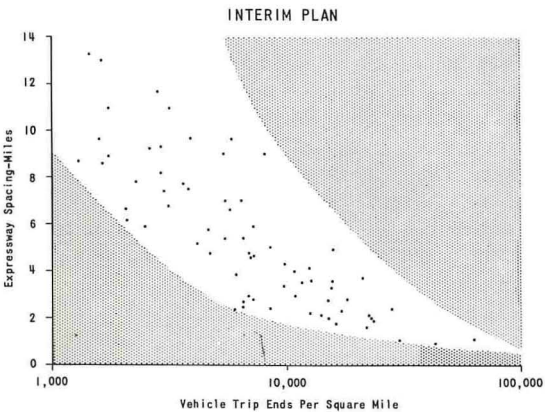


Figure 7. Expressway spacing versus vehicle trip end density with alternate plan 1.

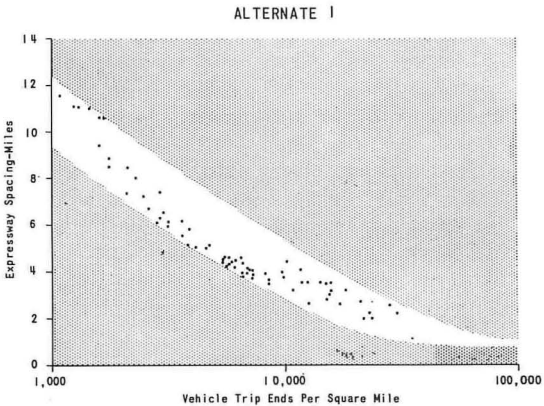


Figure 8. Expressway supply with interim plan.

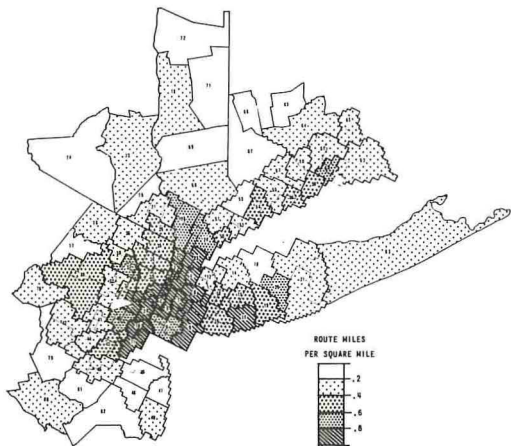
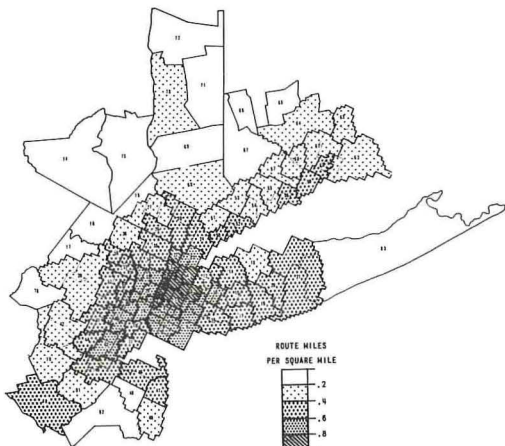


Figure 9. Expressway supply with alternate plan 1.



portion of total travel served by expressways, total travel time and accidents throughout the region, and overall user costs.

Table 1 gives a summary of this information for each of the 4 major subareas in the region—New York City, New York suburbs, New Jersey, and Connecticut. On a region-wide basis, alternate plan 1 out-performs the interim plan with respect to each of these measures. It provides savings of 90,000 vehicle-hours and 60 accidents/day. These savings, worth about \$320,000/day, are obtained, but total vehicle-miles of travel is increased by about 4 million vehicle-miles per day. This improved performance derives from the increase in the proportion of total travel on expressways from 34.4 to 37.2 percent. A more detailed review indicates that savings are achieved in every major subarea except New York City where time and accidents increase while vehicle-miles of travel decline. This is a direct result of reallocation of a large portion of funds from New York City to use in other areas. The implication of this shift is that the costs of locating additional expressways in portions of New York City are too great to be justified by the highway user benefits that would be generated. Separate analysis should be aimed at determining the extent to which other highway or nonhighway improvements can provide required travel service. Account must be taken of the equity implications of concentrating express highway investment in low- and moderate-density areas and the corresponding need for alternative transportation service in the central portions of the region.

In view of the practical limitations of reallocating funds across major political boundaries, a second analysis was undertaken to determine the optimal allocation of funds based on budget limitations for the subareas. Each budget limitation was based on the estimated cost of the construction specified in the interim plan for that sub-regional area. This reallocation of capital is referred to as alternate plan 2. The results of this analysis are also given in Table 1. In terms of the region-wide estimates of vehicle-miles of travel served, average travel speed, average accident rate, and overall average cost, alternate plan 2 falls between the interim plan and alternate plan 1. The overall savings that would be achieved by substituting this plan for the interim plan are approximately two-thirds as great as those that would be obtained by adoption of alternate plan 1. This plan has the advantage of providing improved performance over the interim plan in each major political area including New York City.

Resource Allocation

An indication of the differences among alternatives may be seen by comparison of the allocation of resources to subregional areas. Table 2 gives this allocation for each major subregional area for all 3 plans in terms of capital investment, route-miles of new expressways, and resulting total route-miles of expressways. The differences for alternate plan 1 are a large reduction in the allocation to New York City, a significant increase in New Jersey, and modest increases in the New York suburbs and Connecticut. Because of the a priori restrictions on alternate plan 2, it has a similar fund allocation to the interim plan at this scale of analysis. However, relocation of some investment among the counties within each major area results in greater route-miles of new expressways. The total addition to the expressway system increases in both alternatives as a result of this redistribution.

The overall result is to shift funds from those areas with relatively low marginal benefits to areas of higher marginal benefit. Figure 10 shows the marginal rate of return that would prevail in each county based on the interim plan. The wide variation—from less than 10 percent to more than 16 percent—demonstrates the degree of imbalance in the plan. The diversion of funds is largest from the low return areas such as New York City, to the high return areas of New Jersey.

The region-wide marginal rate of return that will prevail for alternate plan 1 will be 12.8 percent. For alternate plan 2 the marginal rates of return would vary by major areas as follows:

<u>Area</u>	<u>Percent</u>	<u>Area</u>	<u>Percent</u>
New York City	9.0	New Jersey	14.4
New York suburbs	12.9	Connecticut	13.7

Table 1. Performance comparison of interim plan and alternate plans 1 and 2.

Subarea	Daily VMT (millions)			VMT on Expressway (percent)			Expected Daily Accidents			Daily Travel Time (millions of hours)			Average User Cost/VMT (cents)		
	IP	AP1	AP2	IP	AP1	AP2	IP	AP1	AP2	IP	AP1	AP2	IP	AP1	AP2
New York City	39.2	37.6	39.9	46.0	41.2	48.3	465	481	457	2.04	2.07	2.03	18.2	19.3	17.8
New York suburbs	91.1	91.6	91.4	33.2	34.7	34.1	673	660	663	3.87	3.85	3.85	13.3	13.2	13.2
New Jersey	99.4	103.5	100.4	32.0	38.9	34.2	877	825	859	4.75	4.67	4.72	15.1	14.2	14.9
Connecticut	41.3	42.0	41.6	32.0	35.2	33.5	303	295	299	1.76	1.76	1.76	13.4	13.1	13.3
Region	271.0	274.8	273.3	34.4	37.2	36.1	2,319	2,260	2,278	12.43	12.34	12.37	14.7	14.4	14.5

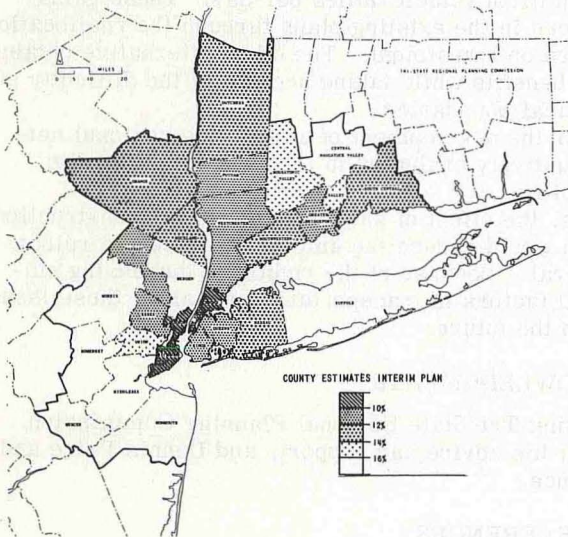
Note: Changes in route-miles of expressway are given in Table 2. Totals may not add because of rounding.

Table 2. Allocation of resources under different alternatives.

Subarea	Capital Investment (millions)			Expressway Route-Miles Added			Total Expressway Route-Miles		
	IP	AP1	AP2	IP	AP1	AP2	IP	AP1	AP2
New York City	2,100	800	2,100	119	68	144	311	259	335
New York suburbs	1,900	1,950	1,900	404	433	411	916	946	924
New Jersey	3,300	4,400	3,300	535	750	595	751	966	811
Connecticut	900	1,050	900	190	241	217	379	430	406
Region	8,200	8,200	8,200	1,248	1,493	1,367	2,357	2,601	2,476

Note: Totals may not add because of rounding.

Figure 10. Marginal rate of return from increased highway construction.



For alternate plan 2 the marginal rate of return remains constant within each sub-area. The high rate of return indicated for New Jersey and Connecticut illustrates that there are additional investment opportunities that would achieve greater savings than the region-wide average rate. The reverse condition exists in New York City indicating that some of the accepted investments should be reconsidered as they are earning benefits at less than the region-wide average rate. (No benefits are included for the value of connecting regional facilities through the core of the region in this analysis, but neither has there been an estimation of community disruption costs due to new construction in high-density areas. Explicit inclusion of such costs and benefits would improve the completeness of the analysis.) These remaining variations in return on investments are indicative of the imbalance that will remain in the system if political boundaries act to restrict investment alternatives. In all 4 subareas, there are numerous changes among the individual counties (planning regions in Connecticut) that can be traced to the analysis areas shown in Figure 1. No general conclusion as to the overall funding level may be made based on this analysis as certain costs (household relocation, community disruption, and traffic disruption during construction) have not been included in the analysis. The inclusion of these costs might lead to a significant reduction in the region-wide rate of return, although it is our contention that such reduction would preserve the general pattern of differences among alternatives.

SUMMARY AND CONCLUSIONS

This paper describes an approach to evaluating the allocation of funds for highway capital investment based on a quantitative objective function and a highly aggregate model describing highway system performance. The evaluation indicates a significant imbalance in the existing interim plan for 1985.

The analysis has resulted in the development of alternative plans for resource allocation that will provide improved travel service and lower user costs within the same capital budget required for completion of the interim plan. The more efficient of these alternatives offers travel cost reductions valued at more than \$320,000 daily while supporting additional travel of 4 million vehicle-miles per day. These gains are achieved by elimination of imbalances in the existing plans through the reallocation of funds from areas of low to high return on investment. The other alternative obtains approximately three-quarters of these benefits while taking account of the difficulty of redistributing funds across major political boundaries.

The analysis provides a guideline for the development of alternative regional networks; the guideline can be more exhaustively evaluated in terms of user benefits, community impact, and financial feasibility.

Although not included in the analysis, the effect of shifting expressway construction to less developed portions of the region would reduce the amount of household relocation and community disruption, in general. Because of the rightfully increasing emphasis on community and environmental factors in transportation planning, these issues will have to be treated more directly in the future.

ACKNOWLEDGMENTS

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PROPOSED LOGIC SEQUENCE FOR DESIGNING PRELIMINARY URBAN LAND USE PLANS

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A formulated design concept is presented, and its potential role in the preparation and evaluation of alternative preliminary land use plans is described. The concept fundamentally aggregates a system of required land use activity space-time contents into subsets subject to certain design constraints. A second generation computer program that utilizes the aggregation concept is described. The 2 major components of the program are an activity subset formation routine and an activity location routine. The activity subset formation routine aggregates the activity into subsets subject to their participation order, duration times, and interactivity compatibility relations. The routine also generates the trip-time frequency distributions. The activity location routine places the required activity land use spaces into a location matrix subject to the transport ranges and the interactivity and activity-to-existing-environment compatibility relations. A priority is placed on filling existing vacant land use spaces before creating new space. The activity location routine plots a graphical representation that identifies the types and locations of the land uses and the transport links. The routine determines the amount of land use space to be supplied and the amount of excessive space supplied. An example output from an experiment using a 400-household schedule is illustrated.

• A SECOND generation logic sequence is described for heuristically allocating urban structural space as a function of the population's daily or weekly physical activity patterns. The description is preceded by a brief review of the formulated design concept. The theoretical background of the concept and first generation logic sequence is described in other reports (1, 2). The concept involves the aggregation of a system of activities as represented by their required space-time contents into subsets subject to certain land use and transport constraints. The logic sequence attempts to utilize the concept for the purpose of aiding in the preliminary synthesis of urban structural space.

The synthesis of urban space basically consists of the determination of the number, sizes, and locational arrangement of the various types of user spaces to be supplied based on the forecast spatial requirements of the particular population. The objectives of the concept and logic sequence as design aids are to (a) translate the forecast system of spatial requirements into a graphical representation in accordance with a set of design standards; (b) provide units of measurements that have the potential for being extended for the purpose of evaluating the plan; (c) create alternative plans by the exogenous adjustment of any of the determinants; and (d) reduce the number of alternative plans to a number that can be analyzed and subsequently synthesized in greater detail by more exact methods.

The logic sequence and its associated computer program are composed of an activity subset formation routine and an activity location routine. The activity subset formation routine attempts to maximize the temporal utilization of space by aggregating the activities into subsets subject to their participation order, duration times, and interactivity compatibility relations. The routine also generates the trip time frequency distributions.

The activity location routine attempts to maximize the utilization space by placing the required activity land use spaces into a location matrix subject to the transport

ranges and the interactivity and activity-to-existing-environment compatibility relations. A priority is placed on fitting the existing vacant structural space before creating a new one. The routine output is a graphical representation of the structure including the transport links and the amount of structural space created and the excess amount supplied.

A number of formulated models have been developed for spatially allocating urban activities and their associated spaces. The major deficiencies of these models are that (a) they appear to be unduly influenced by the historical and contemporary form of the urban structure for synthesizing and, therefore, inhibit the study of the introduction of innovations in transport and building technology; and (b) at best they only indirectly recognize that activities are undertaken for short intervals of time during a time period. Greater temporal and spatial utilization of public structural spaces such as transport might be achieved by regrouping the activities, resizing their space requirements, or rearranging their locations or doing all of these.

BRIEF DESCRIPTION OF THE DESIGN CONCEPT

The urban phenomenon for the purpose of design is viewed as a physical instrument evolved by man by which he attempts to more efficiently satisfy his own self-perceived individual and collective psychological and biological needs. These needs are a manifestation of his voluntary and involuntary interaction with an imperfect environment.

The man-environment interaction is operationally conceptualized as a system of human physical activities. The system of activities is engaged in during a period of time. Each activity is associated with an individual and requires a known amount of space and time in order to be undertaken successfully. Structural space is to be supplied and maintained for each activity for the time period that the system of activities is undertaken.

Resources are expended, supplying and maintaining structural space. If it is assumed that the total amount of resources available to the population at any point in time is limited, then that which is expended to create and maintain structural space cannot be used for participating in the activities for which the space is supplied.

Resources are misallocated if the amount of structural space supplied or the amount of time that the space supplied for each activity or both of these are in excess of that required. An excessive amount of space is supplied if the activities are spatially and temporally undertaken independently of each other and if the minimum amount of space supplied and the minimum amount of time that the space is available are greater than that required by each individual to engage in the activity successfully.

The degree to which the structural space is utilized is assumed to be capable of being expressed as the total sum of the difference between the product of the amount of structural space supplied and the amount of time it is supplied and the product of the amount of space required and the amount of time it is required by an activity or a system of activities. The difference is termed the wasted space-time content. Wasted space-time content is an indication of the operational efficiency or performance of the urban structure. The urban structure is inefficient if it is high and efficient if it is low.

The objective is to maximize the utilization of the structural space by minimizing the total amount of wasted space-time content. The total amount of wasted supplied space-time content can be reduced if the total amount of supplied space-time content is decreased. The total amount of supplied space-time content can be decreased if the activities and their associated required space-time contents are grouped or formed into subsets at any point in time or space, i.e., minimize W , where W is the total amount of wasted space-time content supplied and where

$$W = N \times f_k \times T - \sum_{k=1}^N \left\{ \sum_{(a_i) \in k} [x_{(a_i)k}] [\phi_{(a_i)} \tau_{(a_i)}] \right\}$$

where (a_i) is a finite, discrete, and unique activity, such as manufacturing, shopping, or household, that is associated with a particular individual j , exhibits scalar characteristics of a certain magnitude, and has meaning in space allocation. Each activity is

composed of an elementary transport activity (a_i^t) and an elementary land use activity (a_i^l); i.e., $(a_i) = [(a_i^t), (a_i^l)]$. Also, in $(a_i) \in U$, U is the universal set of activities undertaken by the urban population composed of Q number of people such that $U = [(a_1), (a_2), (a_3), \dots, (a_H)]$ and $H = \sum_i (a_i)$, the total number of activities undertaken, where $i = 1, 2, 3, \dots, H$.

Also, $H \gg Q$ and therefore $Q = \sum_i s_j$, where $j = 1, 2, 3, \dots, Q$ and where s_j is the particular schedule of activities of individual j such that $s_j = [(a_1), (a_2), (a_3), \dots, (a_g), (a_1), \dots, (a_p)]$, where $(a_1) \rightarrow (a_2) \rightarrow (a_3), \dots, \rightarrow (a_g) \rightarrow (a_1), \dots, \rightarrow (a_p)$ and $(a_i^t) \rightarrow (a_i^l)$. The urban-wide activity schedule $S = (s_1, s_2, s_3, \dots, s_j, \dots, s_Q)$, which for purposes of design is engaged in a cyclical or repetitive manner.

$\tau_{(a_i^l)}^j$ is the finite, discrete, and unique amount of time required by individual j in order to engage in the elementary land use activity (a_i^l) and $\tau_{(a_i^l)}^j \in \tau_{(a_i^l)}$, where $\tau_{(a_i^l)} = \tau_{(a_i^t)} + \tau_{(a_i^l)}$, where $\tau_{(a_i^t)}$ and $\tau_{(a_i^l)}$ are respectively the finite, discrete, and unique amounts of time required by individual j in order to engage in the activity (a_i) and the elementary transport activity (a_i^t).

$\phi_{(a_i)}$ is the finite, discrete, and unique amount of space in the form of a horizontal square area required by individual j in order to engage in the activity (a_i). The area is determined by summing all of the area requirements of the lower orders of activities and expressing the total as an equivalent amount of ground space. Also, $\phi_{(a_i)} = \phi_{(a_i^t)} + \phi_{(a_i^l)}$, where $\phi_{(a_i^t)}$ and $\phi_{(a_i^l)}$ are respectively the amounts of space required to engage in the elementary activities (a_i^t) and (a_i^l). The amount of transport space $\phi_{(a_i^t)}$ is defined

as that required for immediate access and $\Phi = \sum_{i=1}^H \phi_{(a_i)}$, where Φ is the total amount

of space required by the population Q to engage in the system of activities. The remainder of the transport space required is defined as a straight line representing the transport range or distance of the elementary transport activity, $d_{(a_i^t)} = v_{(a_i^t)} \times \tau_{(a_i^t)}$, where $v_{(a_i^t)}$ is the average straight-line velocity of the elementary transport activity (a_i^t).

k is a finite and discrete object called an urban activity subset, such as industry, retail, or neighborhood, that is composed of one or more activities; i.e., $k = \sum_{(a_i) \in k} (a_i)$ and $k \in \Omega$, where Ω is the family of subsets such that $\Omega = (k_1, k_2, k_3, \dots, k_N)$.

f_k is the finite and discrete amount of structural space supplied for the land use activity subset k and $f_k \geq \phi_{(a_i)}$ at each and every point in time. It is defined for computational simplicity as being square in shape and of a constant area regardless of the type or class of urban activity for which it is being supplied. The amount of transport range supplied, D_{jk} , is a finite and discrete straight line in the form of a single path or roadway or a subsystem of connected paths joining the centroids of 2 supplied land use structural spaces f_j and f_k , where $(a_j) \in J$ and $(a_i) \in k$. Also, $d_{(a_i^t)} = D_{jk}$ at each and every point in time, where lower limit \leq upper limit. Stated otherwise, the supplied land use spaces f_j and f_k must be located spatially relative to each other such that the elementary transport ranges $d_{(a_i^t)}$ are equal to the centroidal distance D_{jk} within prescribed tolerances.

T is a finite and discrete amount of time, such as a day or a week, that the structural space f_k is supplied for activity subset k . The urban-wide schedule of activities S and each of the individual schedules s_j are undertaken during the time period such

that $T = \sum_{(a_i) \in S_j} \tau_{(a_i)}$, $Q_T = \sum_{i=1}^H \tau_{(a_i)}$, and $T \geq t_{(a_i)}$ at each and every point in space.

$x_{(a_i)k}$ is the complementary relation between (a_i) and k , where $x_{(a_i)k} = 1$ when (a_i) is compatible with k , and $x_{(a_i)k} = 0$ when (a_i) is not compatible with k .

The relation encompasses those characteristics that are primarily of a subjective nature. A home-living activity, for example, is complementary to a neighborhood or a residential area but not complementary to a commercial or industrial area regardless of the spatial or temporal compatibilities. The relation can also express locational constraints or attributes other than transport range such as existing structural

investments, higher priority design commitments of a prescriptive nature, or amenable physiological land features. The relation has precedence and is capable of being expanded such that $x_{(a_1)k} = [x'_{(a_1)k}] \times [x''_{(a_1)k}] \times [x'''_{(a_1)k}]$, and so on, where $x_{(a_1)k} = 1$, when and only when $[x'_{(a_1)k}]$, $[x''_{(a_1)k}]$, and $[x'''_{(a_1)k}]$ are each equal to unity where each is a requirement that must be satisfied before (a_1) and its associated space-time content $\phi_{(a_1)} \times \tau_{(a_1)}$ can be assigned to activity subset k and its associated space-time content $f_k T$.

N is the number of activity subsets (k), the number of subsets of required space-time contents $\left\{ \left[\sum_{(a_1) \in k} (\phi_{(a_1)} \cdot \tau_{(a_1)}) \right]_k \right\}$, the number of structural space-time contents supplied ($f_k \times T$) and the number of structural spaces supplied (f_k).

If it is assumed that f_k , T , $x_{(a_1)k}$, $\phi_{(a_1)}$, and $\tau_{(a_1)}$ are given and remain invariant and that $f_k \geq \phi_{(a_1)}$ and $T \geq \tau_{(a_1)}$ and are the minimum and maximum amounts, then the total amount of wasted space-time content W assumes its minimum value when the number of supplied structural spaces N reaches its minimum value subject to the following:

1. S (and, therefore, H and Q) are given;
2. $T = \sum_{(a_1) \in S_j} [\tau_{(a_1)}^t + \tau_{(a_1)}^b]$;
3. $x_{(a_1)k} = 1$ or 0 ;
4. $T \geq \sum_{(a_1) \in k} \tau_{(a_1)}$ at each and every point in space;
5. $f_k \geq \sum_{(a_1) \in k} \phi_{(a_1)}$ at each and every point in time; and
6. $d_{(a_1)}^t \approx D_{jk}$, where $v_{(a_1)}^t$ and $\tau_{(a_1)}^t$ are given and all remain invariant and are satisfied.

LOGIC SEQUENCE AND COMPUTER PROGRAM

The operational objective of the design function is as follows: Given a set of structural space-time contents of an invariant and constant shape and size, determine the minimum number that must be supplied by assigning the maximum number of invariant required space-time contents to each structural space, subject to a set of constraints. The problem thus falls within the general classification of an assignment problem. It is a member of a particular group that is highly combinatoric in nature.

The problem in many respects is analogous to that of assembly-line balancing (3, 4, 5) and the relative location of facilities (6). It is essentially a combination of the two. Characteristically, at this point in time it is not computationally practical to enumerate the number of potential combinations of required space-time contents because the number is so great. This stems from the fact that there are potentially a large number and variety of individual schedules and spatial locations. Just how many types of individual schedules there are that would influence space allocation is not known. There may be fewer types because of man's socioeconomic interdependency and the natural environment's control over his psychobiological mechanism.

The potential number of combinations is also dependent on the degree of detail wanted. The restrictions of order, range, shape and size of structural space, and land use activity time and compatibility reduce the number of potential combinations. The only feasible method of solving the formulation appears to be with a heuristic routine. The routine contained in the logic sequence is a second generation routine. It is an attempt to improve on the operational efficiency of the first one developed (1). The major differences between the 2 models are that the second one has been restructured such that the heuristic routine is subdivided into 2 routines and the compatibility index is expanded. The major results of the modifications are that program accessibility is improved, the execution time is reduced, and the model is more comprehensive.

The program is composed of 8 major components: raw data file, primary setting up routine (SETUP I), primary input file, design criteria file, activity subset formation routine (SUBFOR), secondary setting up routine (SETUP II), secondary input file, and activity location routine (ACTLOC). The procedure by which the components are

utilized is shown in Figure 1. Two assumptions are made in order to simplify the description; (a) Only one mode of transport is considered, and (b) the trips are all home-based.

Raw Data File

The raw data file is composed of information that describes the urban-wide schedule of activity participation. It is assumed to be representative of the activities undertaken by the population during a finite and discrete design time period, such as a day or a week, and is invariant. The information would be generated from trend studies of longitudinal transportation origin-destination home-interview data if the plan is designed for some future horizon year.

The information in the file is structured in the form of family or individual schedules or both. Each schedule is described in the following manner: family or household identity number, identity number of the individual schedule, identity number of the land use activities engaged in by the individual, order of activity participation, and elementary transport and land use activity times.

The activities must be identified and described by the use of a classification system that accounts for various qualitative and quantitative activity requirements for space. For example, an activity described simply as work is not sufficient. It is necessary to describe the kind of work involved, such as retailing or manufacturing.

SETUP I

The primary setting up routine, SETUP I, draws a portion of the information contained in the raw data file and deposits it in the primary input file. The routine transfers the family and individual identity numbers. The identity of each activity in each individual schedule is transferred and is assigned a unique identity number. The preceding activity engaged within each schedule is identified, and its unique number is placed in the primary input file. The procedure continues until all of the activities in the raw data file have been transferred.

The routine scans the raw data file and identifies the smallest elementary activity time (land use or transport). This value becomes the smallest interval of time. The elementary activity times are extracted from the raw data file, normalized, and rounded off to the nearest whole interval of time and deposited in the primary input file. When all of the elementary activity times have been transferred, the normalized times of each individual schedule are checked and, if necessary, adjusted to ensure that they sum to the time period. The start time of each elementary land use activity is determined and entered in a separate column of the primary input file.

Primary Input File

The file is composed of a number of rows; each row represents an activity undertaken by an individual. Each activity is described with the following information:

<u>Information</u>	<u>Column</u>
Identity number of the family or household	1
Identity number of the individual schedule	2
Land use activity identity number	3
Unique identity number of the activity	4
Unique identity number of the preceding activity	5
Normalized elementary transport activity time	6
Normalized elementary land use activity time	7
Elementary land use activity start time	8

One or more rows of activities constitute an individual schedule. The number of rows is dependent on the number of activities engaged in by the individual during the time period. The activities are ordered in rows from top to bottom within each individual schedule in accordance with their participation order.

One or more sets of rows form a family schedule. The number of rows should equal the total number of activities undertaken by the population or its representatives during the time period. The identity of the family and individual schedules is necessary for it ensures that the household activities can be separated one from the other and that each family is supplied a unique structural space.

Design Criteria File

The design criteria file contains data that are capable of being manipulated by the designer in order to generate alternative plans. The information in the file is as follows: amount of land use space required by each type of activity, velocity of transport, and activity-to-activity and activity-to-existing-environment compatibility indexes.

The information is determined from trend studies. The amount of land use space required includes the following, in addition to the net space required: space for transport accessibility; space for demands that occur outside the time period under consideration; and space for lower order activities that are not considered overtly, such as space for playgrounds, primary schools, or churches for the household activity.

An average transport velocity is used initially. Various velocities representing either different modal or different linkage characteristics can be used for finer adjustments of the land use plan. The modes to be used and their potential operating velocities would have to be determined.

The activity-to-activity and the activity-to-existing-environment compatibility indexes are a function of many factors that are very imperfectly understood. This aspect of the design is as a consequence of a subjective nature. The role of the indexes from a design point of view is that they provide the planner with an opportunity to readily test various mixes of activities and generally retain control of the program.

Land Use Activity Subset Formation Routine (SUBFOR)

The purposes of the routine are to determine the minimum feasible amount of structural space to be supplied and the approximate size of the structural land use subset to be supplied.

Because each and every land use activity is to be supplied structural space, then the minimum feasible amount of structural space to be supplied is equivalent to the minimum amount of space required. The amount of structural space is termed the minimum feasible because it is determined exclusive of the constraints of transport range, existing investment, and physiological characteristics of the land.

The routine determines the minimum amount of space required in the following manner.

1. The routine extracts the household-to-household land use activity subset compatibility index from the design criteria file and by scanning columns 1 and 3 of the primary input file accumulates the number of household activities undertaken subject to each family or individual being engaged in a household activity once and only once during the time period. This number is stored by the routine.

2. The routine then extracts the first nonhousehold-to-nonhousehold subset compatibility index from the design criteria file and by starting at time 0 of the time period scans columns 3 and 8 of the primary input file to determine the number of participants in the activity subset at each interval of time. The maximum number of participants engaged in the activity subset at any single interval of time is identified and stored by the routine. The procedure is repeated for each compatible nonhousehold activity subset until all of the activities in the primary input file have been assigned.

3. The routine then totals the peak numbers of participants engaged in each non-household activity subset and in turn adds this to the number of household activities determined in step 1. The value determined is the minimum feasible number of land use subset spaces required by the population. The minimum amount of space required is determined by successively multiplying the peak number of participants engaged in each activity subset by the appropriate unit amount of land use space required from the design criteria file and then totaling the products. The minimum feasible amount of

wasted space-time content is determined by summing the products of the amounts of structural spaces for each activity subset and the differences between the values of the time period and the average activity time required by the participants in order to engage in each activity subset.

The routine determines the approximate size of the structural land use subset to be supplied in the following manner.

1. The routine draws the first nonhousehold-to-nonhousehold compatibility index from the design criteria file and by beginning with the lowest trip-time interval scans columns 3 and 6 of the primary input file and determines the total number undertaken during the time period. The procedure is repeated for each successively larger interval of trip time until all of the elementary transport activities of the subset have been aggregated. The procedure is then repeated for every other nonhousehold activity subset, and the results within the routine are recorded.

2. The routine next identifies the land use activity subset associated with a particular interval of trip time that has the smallest number of participants. The routine extracts this number and divides it into the total number of household activities engaged in and the total number of each nonhousehold activities of each trip-time duration engaged in. When the normalizing is complete, the individual number of participants in each trip-time subset is rounded off to the nearest integer.

3. The routine determines the minimum structural land use subset to be supplied by extracting the amount of space required for each household from the design criteria file and multiplying it by the number of households in a subset determined above. The maximum holding capacity of the nonhousehold subsets can be determined by dividing the size of the supplied structural subset by the appropriate amount of space required contained in the design criteria file.

4. The maximum size of structural subset is determined by extracting the transport velocity from the design criteria file and multiplying it by the smallest interval of trip time. Should this value be smaller than the value determined in step 3, then the alternatives to rectifying the situation are (a) to decrease the amount of elementary land use space required, (b) to increase the velocity of transport, or (c) to arbitrarily reduce the subset size and rework the trip-time frequency distributions and the maximum holding capacities, or (d) to do all of these.

SETUP II

The secondary setting up routine creates the location matrix by (a) extracting the minimum feasible amount of space required from SUBFOR and increasing the amount by a factor of 2 to 5 to take into account the space that will be wasted, (b) extracting the subset size from SUBFOR and creating a grid (cells), (c) determining the location of the cell centroids and numbers the cells in order starting at the center cell and spiraling outward, and (d) utilizing a plotter routine to present a graphical output.

The existing investment to be retained and the physiological features of the land are exogenously mapped onto the location matrix. The degree to which each cell is compatible or incompatible with the various land use activities is determined. If the design problem is one of expanding an existing urban structure and the schedule is representative of the anticipated population increase, then the degree to which the existing structure is capable of being utilized more completely is determined. The minimum feasible amount of space required in the expansion problem is the sum of the amount of existing structural space being utilized and will be retained and the minimum feasible amount of space required by the additional population. When all of the cells have been classified and the holding capacities of the existing investment have been determined, the information is placed into the secondary input file.

Secondary Input File

The secondary input file is the location matrix. Associated with the file is a plotter routine that will present a graphical output after the activities have been transferred from the subset formation routine by the activity location routine.

Figure 1. Program procedure.

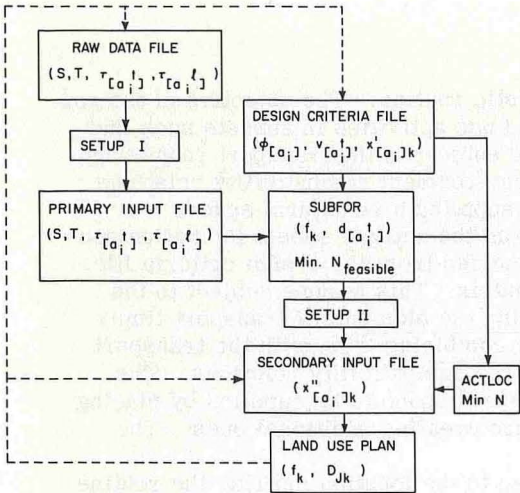


Figure 3. Example land use plan.

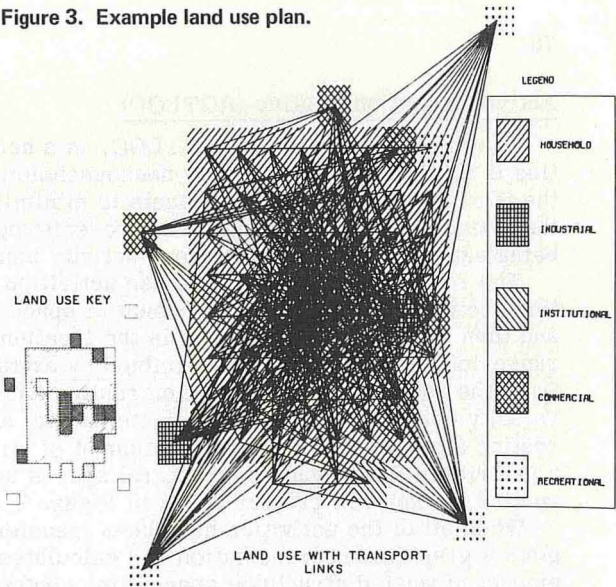
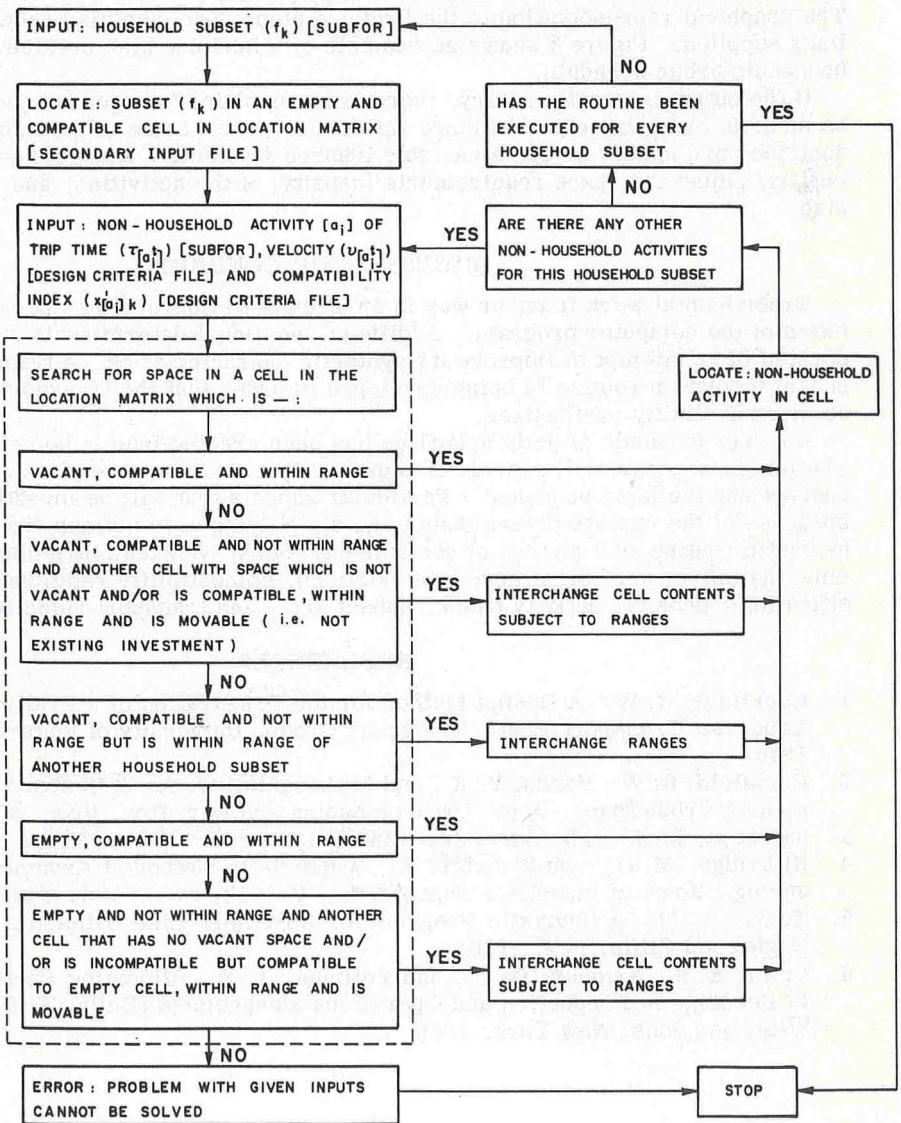


Figure 2. Flow diagram for ACTLOC routine.



Activity Location Routine (ACTLOC)

The main-line program, ACTLOC, is a heuristic routine. The objective of the routine is to locate the elementary nonhousehold land use activities in subsets such that the number of nonhousehold subsets is minimized subject to the transport ranges and the activity-to-activity and activity-to-existing-environment compatibility relations being satisfied and each and every activity being supplied a structural space.

The routine extracts the land use activities from the activity subset formation routine, combines them with the amount of space required from the design criteria file, and then attempts to place them in the location matrix. This is done subject to the range constraint (which is determined by extracting the elementary transport times from the activity subset formation routine and by combining them with the transport velocity contained in the design criteria file) and the compatibility relations. The routine attempts to minimize the amount of structural space to be supplied by placing a priority of filling vacant structural spaces before creating additional ones. The routine is shown in greater detail in Figure 2.

When all of the activities have been transferred to the location matrix, the routine plots a graphical representation and calculates the amount of structural space, the amount of wasted structural space-time content, and the trip-time distributions for each household subset. (The number of trips per household subset remains invariant.) The graphical representation is the land use plan. The plan also shows the transport links supplied. Figure 3 shows an example of a land use plan created from a 400-household urban schedule.

If the output is unsatisfactory, there are a number of exogenous decisions that can be made in order to achieve a more satisfactory one. Some of the more readily applied decisions are modify or use a variable transport velocity, change the compatibility relations, adjust the space requirements (density) of the activities, and modify the subset size.

DISCUSSION OF CONCEPT

Experimental work is under way in an attempt to improve the operational characteristics of the computer program. Additional locational determinants are being incorporated in an attempt to improve its synthetic characteristics. A transport activity subset formation routine is being developed in order that the transport network can be more explicitly synthesized.

A larger schedule of daily activities has been created from a home-interview study. The larger schedule will provide an opportunity for a more complete evaluation of the concept and the logic sequence. Particular aspects that will be investigated are the influence of the various determinants and simplifying assumptions and the use of a heuristic routine as a method of assignment. Sensitivity tests are planned to determine the influence of the precedence relations, compatibility relations (activity classification), density, activity times, subset size, and transport velocity.

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PENNDOT'S TELECOUNT SYSTEM

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The telecount system introduced in 1971 marks the culmination of PennDOT's efforts in developing, installing, and operating a centralized statewide digital traffic reporting and processing system. It improves data flexibility, eliminates reporting time lag, and provides heretofore impossible remote monitoring capabilities. Considerable research was involved in reevaluating the original manual concept and station distribution toward interfacing the existing detection equipment, the land-line communication links, and the minicomputer peripheral components in an automated system. Some problems were encountered during initial program and hardware exercises and in coordinating the efforts of 17 independent telephone companies scattered throughout the commonwealth to provide continuous "dedicated" line service. Details of the system's operation and its performance through the first 6 months of service are included. Research is continuing in component design to reduce size and improve heat dissipation, flexibility, and reliability of the next generation of equipment. Already new capabilities have been devised to expand the present reporting to include vehicle speed, classification, and axle configuration.

•A CENTRALIZED multistation statewide traffic reporting and processing system was recently installed by the Pennsylvania Department of Transportation. This system consists of processing and transmitting equipment at 67 remote field locations, telephone transmission lines, and central data receiving and processing assembly in Harrisburg.

This report describing the approach to automating traffic data collection efforts should aid others contemplating large-scale automatic reporting systems. It is intended to be comprehensive enough to guide traffic engineers in devising their own programs along the lines followed by Pennsylvania with minimal further research.

The subject is introduced by a brief review of the original traffic data collection concept adhered to before 1970, and the shortcomings inherent in that approach will be presented. There is a description of the reevaluation of the ATR factor groupings, station distribution, and location changes submitted to the Federal Highway Administration before the final network to be incorporated in the new reporting system is selected. The report relates our decision to utilize the on-line, real-time reporting technique and the process of purchasing, installing, testing, and operating the entire telecount system. Finally, it identifies several additional capabilities available for future expansion to report vehicle speed, headway, classification, and axle configuration.

CONTINUOUS TRAFFIC COUNTING

Continuous traffic counting has become such a well-established and important program that the purpose and need for it by those involved in the process and those utilizing the results are taken for granted. For those who are less familiar, a general description of the program and its relation to PennDOT's activities may be valuable.

Continuous counting programs are the basic building blocks from which traffic volumes and traffic characteristics are determined. Once these volumes and characteristics are determined, other less expensive and quicker data collection techniques can be employed to obtain a variety of necessary information for planning, design, accident analyses, maintenance, and programming purposes.

In Pennsylvania, a small sample of 67 stations provides all the continuous counting for the 44,000 miles of state highways. These continuous counts can be grouped into 7 categories depending on the pattern of the traffic, as follows:

<u>Traffic Pattern</u>	<u>Installation</u>			<u>Group</u>
	<u>Photoelectric</u>	<u>Radar</u>	<u>Inductive Loop</u>	
Urban	2	4	7	1
Primary rural	8	3	4	2
Secondary rural	5	-	7	3
Light recreational	3	-	4	4
Moderate recreational	4	2	4	5
Extreme recreational	2	-	-	6
Autumn recreational	6	-	2	7

One group consists of the typical urban counts that remain relatively constant throughout the year but have peak hours in the morning and evening. The extreme recreational pattern has very high traffic volumes in the summer months and week-ends and relatively low volumes at other times. Once all of the samples are grouped, comparisons can be made of volumes for any day of the week and yearly volumes, monthly volumes and yearly volumes, and different yearly volumes. This base is expanded further through the use of some 350 monthly traffic counts recorded for a short period of time (2 to 7 days) each month in a continuing program. Thus, more than 400 count locations grouped into 7 categories provide adequate coverage to determine into which group all state highways fall.

One can then take an inexpensive and very quick short-term count of 24 hours once a year and determine the necessary factors to convert the count into a more significant quantity regardless of the month, day of the week, or location. One is thus able to determine the annual average daily traffic, the most basic and necessary building block for planning and design purposes. One can determine the relation of the peak-hour flow to the average daily traffic (K factors).

Existing traffic volumes and historical trends can be used as a basis for expansion in forecasting future traffic volumes. In fact, even when the number of trips are determined from other means, such as home interviews in transportation studies, traffic counts are still employed as screenline checks to verify the resulting assigned traffic volumes.

Traffic volumes are used not only for broad-scale estimates of traffic (as in transportation studies) to determine project needs and priorities but also for detailed estimates of traffic to be used in the detailed design and improvement of a given facility. Without such figures, of course, it would be impossible to accurately evaluate the adequacy of an existing facility or to predict the capacity for which a future highway should be designed. Based on a given level of service, the ratio of the capacity of the highway to the volume of traffic that exists at a given time can be employed along with other elements to determine the sufficiency of the facility. Deficiencies can correspondingly be pinpointed, evaluated, and aggregated under various systems to determine present and future needs.

When supplemented with classification counts according to vehicle type, traffic counts are necessary also for the structural design of the pavement for they indicate the number of repetitions of heavy-weight axles pounding it in a given period of time.

Vehicle-miles of travel and accident statistics incorporating those figures can also be obtained through a traffic counting program. These data are used to identify haz-

ardous locations that merit safety improvement remedies. In addition, many miscellaneous programs, such as traffic signal installation and evaluation of railroad grade-crossing protection, must have their basis in the continuous counting program.

Aside from the importance within the department for study, design, and other purposes, traffic counts are invaluable to many others. Planning commissions can often monitor and plan growth with the aid of such figures, and many businesses depend on these figures in locating their facilities in the most advantageous areas. It is indeed fortunate that the federal government not only has spurred development of traffic counting programs but also has underwritten them to the extent of providing approximately 75 percent of the cost in Pennsylvania for the basic programs. Federal programs not only provide funding for this work but also properly insist that it be done.

ORIGINAL DATA COLLECTION PROGRAM

The first large-scale, on-line, real-time, centralized, multistation, digital traffic data collection system was inaugurated in Pennsylvania on April 1, 1971. The system was developed to collect, record, and process traffic data gathered simultaneously and continuously from 67 remote locations throughout the commonwealth. This system consists of automatic vehicle-detecting and transmitting equipment at each remote field station, interconnecting telephone lines, and the central data receiving and processing assembly in the Transportation and Safety Building in Harrisburg. The statewide system is shown in Figure 1.

One of the first commercially produced automatic traffic counters began recording traffic in Cumberland County in 1936 (9, p. 1). This was a photoelectric device using a cumulative printing counter. The original automatic traffic recording (ATR) program consisted of 10 of these installations throughout the state. They were serviced weekly by 1 person traveling in the western portion of the state and a second person assigned to the east. The cumulative counter required manual transcription and subtraction of each recorded number from the succeeding number to obtain the hourly traffic volumes. As more installations were added, it was apparent that a direct reading recorder would improve the processing time. A new hourly recorder appeared early in the fifties and quickly replaced the early cumulative models. About this time it also was apparent that many highway facilities undergoing traffic studies carried traffic volumes that exceeded the capabilities of the photoelectric detectors. The subsequent addition of new installations and the need for lane data gradually increased the number of installations to 67 and the number of weekly data tapes to 120 by 1963. The field and support personnel directly responsible for weekly ATR data collection and processing also increased to 11. By this time too, the vehicle detectors had become more sophisticated with the introduction of radar and inductive field devices.

The original ATR stations provided one total hourly traffic volume reflecting the number of vehicles passing the detectors in both directions. Consequently, with 10 installations there were 10 data tapes. With the introduction of lane and directional counts, several selected stations were equipped to provide traffic data for each lane of traffic while other stations were equipped to record combinations of lane counts to represent traffic passing in only 1 direction. Thus, a total of 120 data tapes were reporting the traffic passing the 67 remote field locations.

The average daily traffic is an elementary basis for chronological reporting of the utilization of a specific roadway or the comparison of different roadways. Because it would be extremely expensive and time-consuming to actually count all of the traffic traversing every separate section of roadway throughout the state, the problem is simplified by grouping the various roads having similar characteristics and sampling these with a small number of continuously operating traffic recorders. These locations are strategically located, permanently constructed, and energized from utility company power and communications lines. Factors obtained from data provided by the continuously operating stations enable the engineer to expand relatively short-term machine or manual counts to represent average daily traffic. These short-term counts are obtained from seasonal control and coverage count machine recordings as well as manual classification and turning movement counts.

This information is necessary to satisfy the never ending requests for traffic data for transportation studies, design criteria, traffic control, sufficiency and need studies, commercial roadside development, signalization warrants, accident frequency studies, and capacity studies.

The original reporting process began with the field serviceman removing the data tape and mailing it to the central office (Fig. 2). Field personnel mailed tapes from the nearest district office, and the tapes were usually received in the central office by the following Monday morning. Each tape was arranged for continuous keypunching by sequencing the count data to include a full week's coverage from Monday morning through Sunday midnight. This manual preparation for keypunching required 2 days after which the tapes were carried to the Data Processing Unit where the hour, volumes, station numbers, and date were punched into 2 cards per day per tape, one for a. m. and one for p. m. The cards for the week were then sorted by station and date. Allotted time for this step was 1 week but often ran as long as 1 month. The cards were then run through the computer to produce a magnetic tape and a proof listing. This listing was then sent to the Traffic Records Unit to be edited and analyzed. With corrections, it was returned to Data Processing for additional keypunching. Without corrections, it was sent to Data Processing Control to be entered in the processing log. This step required an average of 1 month. From Control the cards were sent through the Burroughs 5500 computer to produce the weekly and monthly tables (Figs. 3 and 4) and a magnetic accumulative tape for library storage. These forms were reviewed and, if not satisfactory, were discarded and the process repeated. If satisfactory, the process was complete and the appropriate copies were distributed. Time for the final step averaged about 1 month. Total processing time allotted by the Federal Highway Administration was approximately 3 weeks after the end of the month being reported. With these reports requiring more than 3 months for preparation, it was evident that a new approach was urgently needed.

DEVELOPMENT OF AN AUTOMATED SYSTEM

While a new processing technique for automating the central office processing operations was being contemplated, it was apparent that as much of the routine manual field work as possible should be automated. By the mid-sixties, the state of the art in the field of traffic reporting was investigated and it was found that the only system that had been installed and tested under actual traffic conditions specifically for traffic data collection was one operated by the Connecticut Department of Highways. Further investigation revealed that the system had been developed by the Automatic Signal Division of the Laboratory for Electronics and was being tested in cooperation with the Connecticut highway department and the Connecticut Telephone Company (1, pp. 21-34). Progress being made by other states was observed as the needs of the department began taking shape. Three other states, with their own planning bureau computers, had utilized dial-up installations where each remote station stores its traffic data and is polled periodically by the central computer (3, 4, 6). However, one of Pennsylvania's problems was that its system would be appreciably larger than that which any other state had developed to date. Approximately 28 min of each hour would be required for instructions and storage (5). This information was based on discussions with representatives of states using the dial-up method. Early operation with automatic dial-up systems experienced between 10 and 20 percent lost time caused by incorrect responses during polling periods. These include busy signals, wrong numbers, or no answers and thus made the counting periods even more variable depending on the number of stations to be redialed.

A dial-up system would have required replacement of all existing field cabinets and detecting equipment. The new reporting process would consist of cumulative recorders at each location and would have meant a step backward to again require a subtraction operation to obtain the hourly traffic volumes. Previous experience indicated that half of the lost time was attributable to the field recorders. Thus it was advantageous to eliminate the field storage devices.

Figure 1. Statewide communication links and ATR locations.

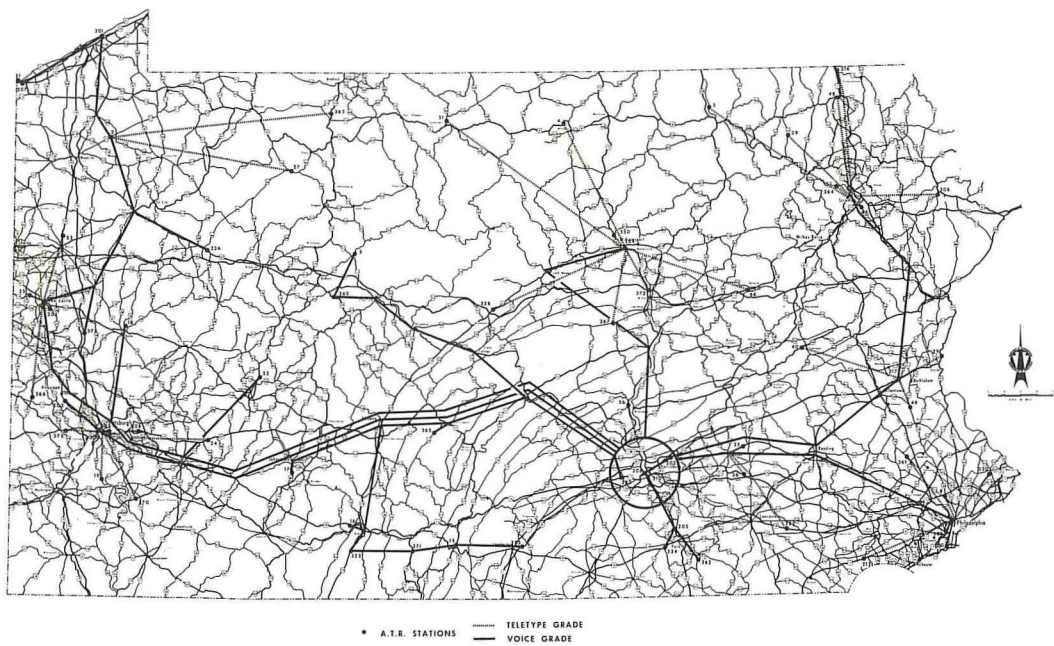


Figure 2. Manual ATR tape processing.

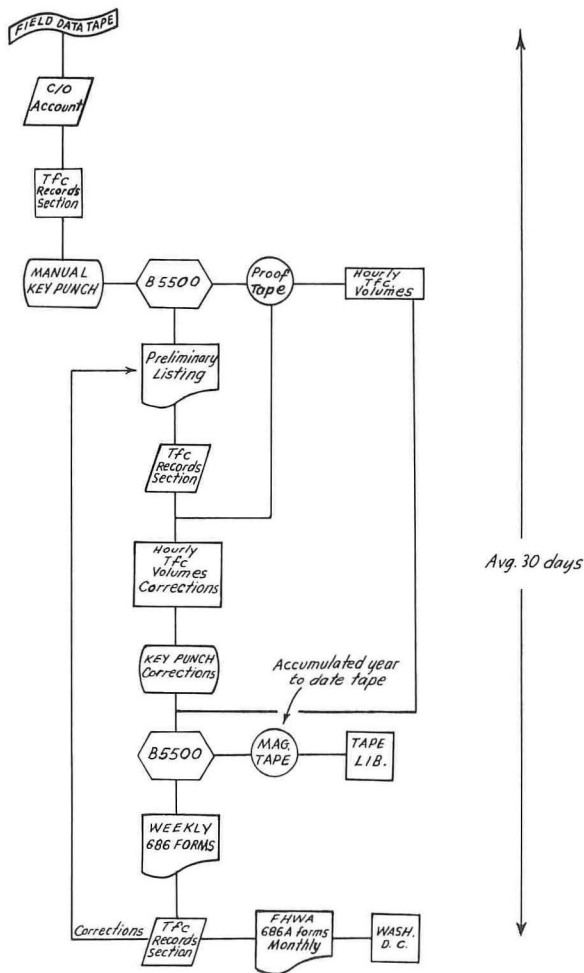


Figure 3. Weekly traffic table.

PS-686 (9-70)		PENNSYLVANIA DEPARTMENT OF TRANSPORTATION					HIGHWAY PLANNING STATISTICS		
LANE ALL		DIR. BOTH	WEEKLY TRAFFIC TABLE NO. 1				STATION 001		
ROUTE US 20		CO. NO. 25	NAME W SPRINGFIELD				WK. BEG. 9/06/71		
DAY	MON.	TUE.	WED.	THUR.	FRI.	AVERAGE WEEKDAY	SAT.	SUN.	7 DAY AVERAGE
DATE	9/06	9/07	9/08	9/09	9/10		9/11	9/12	
12-1	120	78	120	98	95	102	131	123	109
1-2	92	61	76	63	56	69	78	97	74
2-3	65	52	40	46	42	49	72	108	60
3-4	31	33	51	51	50	43	67	62	49
4-5	34	31	43	31	44	36	41	32	36
5-6	24	63	54	71	53	53	41	37	49
6-7	46	178	200	177	188	157	84	57	132
7-8	54	216	204	202	208	176	111	56	150
8-9	69	184	182	160	174	153	179	102	150
9-10	147	215	233	209	254	211	253	178	212
10-11	206	295	258	255	296	262	306	187	257
11-12	289	290	287	234	299	279	374	281	293
12-1	308	315	274	257	338	298	373	392	322
1-2	343	313	243	314	345	311	385	388	333
2-3	375	334	302	353	333	339	381	414	356
3-4	419	372	338	394	415	387	378	403	388
4-5	374	412	363	402	441	398	390	446	404
5-6	392	380	349	336	460	383	345	419	383
6-7	428	309	357	334	411	367	356	392	369
7-8	470	321	304	342	394	366	342	385	365
8-9	386	284	276	278	351	315	360	297	318
9-10	252	211	231	193	256	228	280	197	231
10-11	190	156	184	213	203	189	174	120	177
11-12	114	98	110	96	168	117	139	94	117
TOTAL	5228	5201	5079	5109	5874	5298	5640	5267	5342
%	97.86	97.36	95.07	95.63	109.95	99.18	105.57	98.59	37398
LANE J = SUM OF ODD NUMBERED LANES			LANE K = SUM OF EVEN NUMBERED LANES				*TOTAL 7 DAY VOLUME		

Figure 4. Monthly traffic table.

PS-686A (11-70)		PENNSYLVANIA DEPARTMENT OF TRANSPORTATION					TRANSPORTATION PLANNING STATISTICS		
LANE ALL		DIR. BOTH	MONTHLY TRAFFIC TABLE NO. 2				STATION 001		
ROUTE US 20		CO. NO. 25	NAME W SPRINGFIELD				MONTH 8/71		
WK. BEG.	MON.	TUE.	WED.	THUR.	FRI.		SAT.	SUN.	
7/26								6,164	
8/02	5,614	5,555	5,479	5,737	6,145		6,161	6,170	
8/09	5,646	5,493	5,503	5,568	6,299		5,801	5,836	
8/16	5,623	5,380	5,290	5,541	6,228		6,048	5,914	
8/23	5,459	5,428	5,227	5,319	5,973		5,941	6,238	
8/30	5,498	5,408				WEEKDAYS			MONTH
TOTAL	27,840	27,264	21,499	22,165	24,645	123,413	23,951	30,322	177,686
AV. DAY	5,568	5,452	5,374	5,541	6,161	5,609	5,987	6,064	5,731
LANE J = SUM OF ODD NUMBERED LANES			LANE K = SUM OF EVEN NUMBERED LANES						

Central computer control, processing, and automatic dialing equipment monthly rentals for use in a dial-up system were estimated to be approximately \$4,400, and monthly telephone charges were estimated to be approximately \$1,800 for use with a dial-up system (2).

REMOTE FIELD INSTALLATIONS

By mid-1967, preliminary development of the type of installation required was completed and the overall system, including station distribution and geographical coverage, was discussed with representatives of the Federal Highway Administration. Objectives were to provide adequate continuous traffic data with a limited number of strategically located installations to provide design, trend, and factoring data. The review considered historical coverage as well as coverage of new facilities under construction or in the planning stage (10). The product of this review was the selection of the ATR locations and the data to be reported from each of these locations. This information included the ATR number, type, site description, number of traffic lanes, and number of data inputs to the central office computer. The type of vehicle detectors used at each station is also provided as follows:

Detector	Code
Photoelectric total volume data	PE
Radar installation with only antenna suspended over the roadway	RC
Radar with transmitter and receiver suspended over the roadway	RD
Inductive wire loop installation in road surface	IL

Final confirmation of the locations to be included in the initial telemetry system provided the necessary information to complete the specifications for the computer input capacity. A single reporting input from each of 42 low-volume 2-, 3-, or 4-lane facilities, 2 inputs for directional counts from each of 20 locations, and 1 data reporting input from each traffic lane at 5 expressway locations account for a total of 105 initial data reporting inputs to the computer (8). These replace the 120 data tapes previously reported. The lane-counting facilities will be utilized to provide information for special lane studies in the future. The central office assembly is capable of receiving signals from up to 180 field sensors; therefore, adequate expansion capability is ensured.

COMMUNICATION LINKS

At the remote field installation shown in Figure 1, the photoelectric, radar, or inductive loop detectors provide 1 count for each vehicle detected. Because the photoelectric type must scan the entire width of the roadway, it was necessary to utilize either radar or inductive loops to obtain directional or lane counts. On facilities requiring directional information, 2 techniques are available. If the traffic volume is low on a 4-lane facility, the loops may be installed in each lane and the 2 loops in 1 direction attached to 1 detector. However, if the volumes exceed 900 vehicles per hour, the incidence of simultaneous passings will also be high; an accumulator is then utilized to convert these 2 parallel events to series data. The accumulator accomplishes this by momentarily delaying 1 input to follow the other so that the individual counts will both be recorded. These pulses are 100 msec long for each vehicle, and the repetition rate for the parallel to series conversion is 10 pulses/sec (7).

To obtain lane counts, each loop is attached to its individual detector, which in turn activates its assigned encoder (Fig. 5). The encoder interprets this relay closure from its detector and transmits this to the central office decoder as 1 tone pulse at the preassigned frequency. Where remote locations report to collector stations, the remote station's vehicle detector relay closure is transmitted by the telephone company over a class C teletype grade line to activate the encoder at the collector location. Then the tone pulse representing the detector's relay closure is multiplexed with 19 other frequencies on their way to the central office decoder circuits. There are 5 department maintenance building collector sites and 3 field collector sites.

Although the Bell Telephone Company of Pennsylvania has the prime responsibility of providing the necessary service, the success of the entire undertaking is largely dependent on the cooperation of 17 independent telephone companies scattered throughout the state. The development of the transmission system was the culmination of the unified efforts of all of these independent companies and the Bell System's engineering staff to provide the optimum service with minimum construction and operation costs.

The telephone companies provide 60-Ma service for all remote collector lines, and the collector relays are matched through parallel resistors. The bandwidth of the tone transmissions are designed not to exceed 3 KHz and utilize 20 frequencies between 420 and 2,820 Hz.

To summarize the field interface between vehicle detectors and the telephone facilities where a class C line is provided, the telephone company installs its Western Electric 130 or Lenkurt 25 subset equipment at the remote counting location or the nearest telephone company substation. This equipment transfers the detector output to the collector station where it is multiplexed for transmission to the central office. The telephone equipment at the remote site consists only of a small terminal block and a lightning protector if a class A line is provided and the encoder is connected directly to the detector.

Figure 6 shows a typical photoelectric installation modification to accommodate the additional telephone equipment. The extra cabinets were salvaged from discontinued ATR stations. The M type of housing illustrates the addition of the 4 encoders to provide multiplexing for the RD-2 radar detectors shown in Figure 7. The original paper recorders were connected in parallel to provide both printed field and telemetry reporting during the early installation period.

The communications problem was to transmit real-time vehicular information in the form of constant width pulses from all of the remote field stations scattered throughout the commonwealth to a central office located in Harrisburg. All transmissions had to be keyed for inclusion in the proper data block for later retrieval and processing.

Because the data transmitted emanate from such widely scattered locations, simple radial extension of the individual input channels of the computer was not economically feasible. Some form of shared facility was obviously required. The solution was the logical grouping of the sites into geographic sections served by the existing telephone links. The number of links was determined by type, capacity, cost, and present utilization of telephone links available at that time. As it developed, all service was available at each site except ATR 371 in Fulton County. This link was completed before final acceptance tests were performed for the entire system.

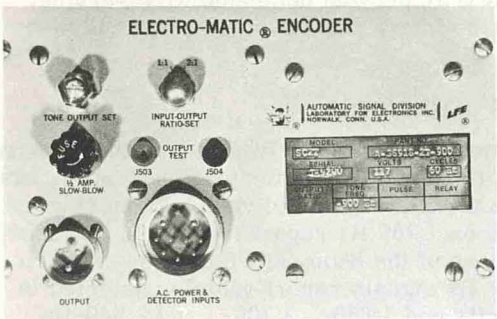
For a closer examination of one of the trunk lines we can look at run 2 from the Pittsburgh area carrying the data inputs listed below to the computer in Harrisburg. Class C lines connect the remote stations to the collector station in the Fort Pitt Tunnel. These 5 stations provide 8 inputs as follows:

<u>ATR</u>	<u>Location</u>	<u>Hz</u>	<u>Input</u>
19	Finleyville	1,980	1
24	New Alexandria	2,580	1
208	Monroeville	2,340-2,460	2
370	Belle Vernon	2,100-2,200	2
375	Imperial	1,500-1,620	2

Within the telephone company's circuitry these tone pulses are multiplexed through the trunk originating at ATR 203 at Leetsdale with frequencies of 1,740 and 1,860 Hz and at ATR 309 at the Fort Pitt Tunnel with frequencies of 1,260 and 1,380 Hz. These frequencies are all added to this same line, 6GM-1037, with the tone pulses from ATR 303 at the Squirrel Hill Tunnel with frequencies 540, 660, 780, and 900 Hz for a grand total of 16 frequencies assigned and 4 vacant for future expansion. Squirrel Hill Tunnel was originally assigned 5 frequencies, but one was discontinued when an experimental peak-hour, lane-reversing procedure was abandoned.

Since all of the telephone installations were made within existing facilities, the only construction necessary for the entire system was the installation of underground service

Figure 5. Tone encoder.



within the department's right-of-way at the Fort Pitt and Squirrel Hill Tunnels in Pittsburgh. Although the telephone companies primarily provide dedicated wire service, they have interconnected radio links in the northwestern portion of the state and these produce equally satisfactory results.

CENTRAL OFFICE FACILITIES

When the tone pulse reaches the central computer, it is received by a decoder board tuned to the specific frequency reporting from the remote field installation. In the case of ATR 309, at the Fort Pitt Tunnel, 1,380-Hz signals report the vehicles entering the downtown area of Pittsburgh. Pulses received on 1,260 Hz report the vehicles passing outbound from the City of Pittsburgh. In the case of the Schuylkill Expressway, ATR 308 in Philadelphia, 1,740-, 1,980-, and 2,220-Hz signals report vehicles detected in lanes 1, 3, and 5 moving westward out of the city and 1,860-, 2,100-, and 2,340-Hz signals report vehicles traveling eastward toward the city in lanes 2, 4, and 6.

The central computer is the brain and operational center of the system. It is located on the ninth floor of the Transportation and Safety Building in Harrisburg. Each input is assigned a separate frequency within each pair of telephone wires entering the central office. There are 7 class A lines and 1 class C line delivering all of the inputs to the decoder assembly.

Storing, processing, and reporting functions are accomplished in a Digital Equipment Corporation PDP-8L minicomputer. Instructions are entered through the automatic send-recvie model 35 teletype machine, and a wide variety of system reports may be obtained by visual display, teletype printout, or punched cards. Information is processed in binary form and is placed in a disk-oriented, real-time operating system. Inclusion and deletion of operational stations, entering and changing of detector titles, setting of short-term report intervals, and system control is handled through the teletype by the operator. Additional functions include a power downtime accumulator for automatic recovery of time, and the validation of gathered data within preselected limits as a function of detector usage type, month, day of week, and hour of day. Out-of-limit counts (based on prior data) are replaced by a calculated value and are reported as being unacceptable.

The disk-operating system allows the computer to process several items at essentially the same time. The teletype may be printing out a daily summary of the total counts for the previous day, the card punch may be punching a partial week's listing of data, and a set of illuminated numbers may be displaying the current number of vehicles in the present hour—all simultaneously.

Data transfers (vehicle actuations) between the Central Processing Unit and the various detector locations are handled on a program-interrupt basis. When a peripheral is ready to receive or transmit data, it signals the Central Processing Unit to begin the transfer process. Detector data are continually scanned at the 50-msec iteration rate (8). The present status of inputs is compared with the previous sample to determine whether or not a vehicle has entered or left the detector. This permits the appropriate counter to be incremented.

Nixie tube clock and calendar displays and a volume count display are linked with the computer. A clock and calendar show the month, day, hour, minute, and second. The time and date can be updated by the operator through the teletype. The Nixie tube volume display shows the current hourly count as it is accumulated for any particular station selected by the operator. One illumination per vehicle detected is also signaled on a wall map display indicating each remote field input (Fig. 8).

Possible power failures will not affect the informational continuity of the system. A downtime accumulator, which is basically a battery-operated clock, records or accumulates the length of time that the central computer has been without power. When power is restored the computer automatically updates the clock and calendar to ensure that data being received are stored in the proper time slots. Accumulator batteries are continuously charged so the unit is always ready for use. Ten hours of downtime a day can be accumulated.

Traffic count information coming into the Harrisburg computer originates at all of the 105 remote detector stations. When a vehicle is sensed, an electrical impulse is generated and relayed to the on-site encoder where it is converted to an "addressed" tone pulse. The encoded actuation is immediately sent out "party line" style over the telephone wire interconnect to a tone receiver or decoder located in the central computer assembly. This unit immediately identifies the origin of each piece of information. From the encoder it reaches the input buffer, which the computer constantly scans for a "change of state." A pulse is sent through only when a vehicle is entering or leaving the detector field to ensure only 1 count per vehicle. All other counts are rejected.

The decoded pulse is now in the computer, which instantly recognizes the data's numerical "address" and transfers it to the computer's core memory for storage. In the telecount system, this means that incoming data are stored for an hour. At the end of the hour, the data are programmed for retrieval for permanent storage. Before the hour count is accepted, however, the data must pass a limit test to prove veracity. From prior observation, there is a known "acceptable" count from each station that is scaled at about the annual average daily traffic level. If the new count is within the ± 50 percent limit, it is accepted and addressed to disk storage. If for some reason, the count is unacceptable, i.e., outside the limit test parameters, a calculated value based on prior station statistics is substituted (Tables 1, 2, 3, and 4). This procedure eliminates the possibility of rare, unrepresentative, and exaggerated counts becoming a significant part of the data. At week's end 168 hours of data for each input are printed out in a single report. In addition, a "substituted" value is shown with an asterisk when the hourly count is printed, showing which particular station was out of line for this period.

Unacceptable values may be caused by variables such as an accident, a flood, or some other occurrence likely to influence traffic.

The counts are put in a format that permits fast and accurate analysis and are provided in 12-hour a.m. and p.m. counts as well as in daily totals and 5- and 7-day average.

All counts are either automatically produced according to a programmer in the memory core or furnished at the operator's command through the teletype. In addition to comparatively long period counts, the operator can ask for a count of from 5 to 60 min from any station, starting at any time. All reports are accompanied by the time, date, and station address. An hourly count, for instance, is available from a selected group of stations in any of the time parameters. In short, the operator tells what traffic count information he wants, and the computer supplies it.

Electronic memory is infinitely reusable. The short-term, hourly, and daily reports recorded are erased when the information is punched into cards or dumped through the teletype.

Accuracy is checked by the operator at any time by means of 10's count test that permits him to isolate incoming data and to verify operations of any part of the central system. This test operation is by relay that cuts off inputs to the tone receivers. Another relay, pulsing at the tail end of the tone receiver board, introduces a count of 10 vehicles for every count station. The computer then administers the test and reads 10 in all channels. It knows what went in and it knows what should come out. The computer's decision is given to the operator through the teletype. When the test is finished, the detector lamps and the computer should agree. If a count shows on the detector board and not in the computer, a computer problem is brought out. Conversely, if a station passes and shows no count, a field problem becomes apparent.

Count totals from the 105 remote stations can be supplied at 5-min intervals, by the hour, day, and week. Auxiliary equipment supplies monthly totals. Each total has its own specific use. The minimum 5-min total can pinpoint peaks in rush-hour traffic. The traffic engineer, planner, or analyst can examine these smaller increments for the precise measurement and evaluation needed for border-line decisions.

The hourly count is the traditional timing unit and is the one most used to divide the "traffic day" into workable segments. Counts by the week and by the month provide the basic traffic "character" profiles that affect medium- and long-range design and planning.

Figure 8. Illuminated wall map in central office.

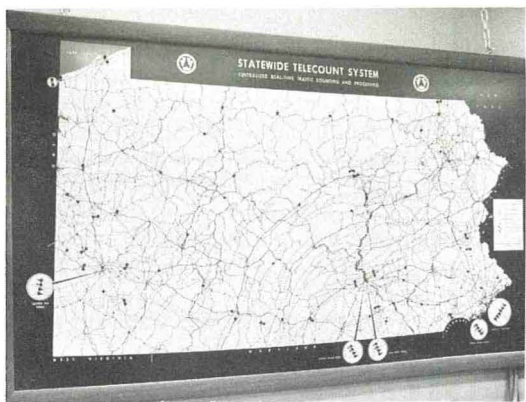


Table 1. Hourly adjustment percentages.

Hour	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7
12-1 a. m.	1.6	1.5	1.4	1.7	1.1	1.2	1.6
1-2	0.8	0.8	0.7	1.2	0.6	0.6	1.0
2-3	0.5	0.6	0.4	1.1	0.3	0.3	0.9
3-4	0.4	0.4	0.3	1.2	0.3	0.2	0.8
4-5	0.4	0.5	0.5	1.4	0.5	0.1	0.9
5-6	1.0	1.3	1.5	1.9	1.1	0.3	1.6
6-7	4.0	4.6	4.9	3.5	3.4	1.0	2.6
7-8	7.3	8.7	6.3	4.3	4.5	2.8	3.2
8-9	6.8	6.7	4.6	4.7	4.5	4.4	4.2
9-10	5.5	4.9	4.8	5.2	5.1	4.8	5.0
10-11	4.8	4.4	4.7	5.7	5.3	6.5	5.7
11-12	4.7	4.3	4.5	5.9	5.4	7.1	6.0
12-1 p. m.	4.6	4.3	4.9	5.8	5.9	7.3	6.2
1-2	4.9	4.5	5.8	6.0	6.5	7.5	6.8
2-3	5.4	5.2	7.2	6.3	6.7	8.0	7.1
3-4	6.7	6.3	8.5	6.8	7.8	8.4	7.6
4-5	8.1	8.6	8.7	7.2	8.2	8.9	8.0
5-6	7.6	8.5	6.7	6.7	8.1	6.6	7.2
6-7	6.0	6.2	5.0	5.9	6.4	5.4	6.0
7-8	4.7	4.5	4.7	5.0	5.5	5.3	5.2
8-9	4.1	3.7	4.2	4.1	4.4	4.8	4.1
9-10	4.0	3.9	4.0	3.5	3.8	3.9	3.5
10-11	3.3	3.1	3.3	2.8	2.8	2.6	2.8
11-12	2.8	2.5	2.4	2.1	1.8	2.0	2.0

Table 2. Daily adjustment percentages.

Day	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7
Monday	104.7	100.7	95.4	92.4	91.7	85.8	95.9
Tuesday	103.4	99.9	93.7	94.5	90.5	86.2	91.2
Wednesday	104.6	102.8	94.3	94.9	87.4	78.9	91.0
Thursday	107.5	103.8	95.9	97.0	94.5	83.7	94.9
Friday	109.9	113.4	112.9	111.3	105.6	103.3	110.9
Saturday	91.3	93.0	110.2	103.3	112.7	104.0	107.3
Sunday	78.6	86.4	97.6	106.6	117.6	122.1	108.8

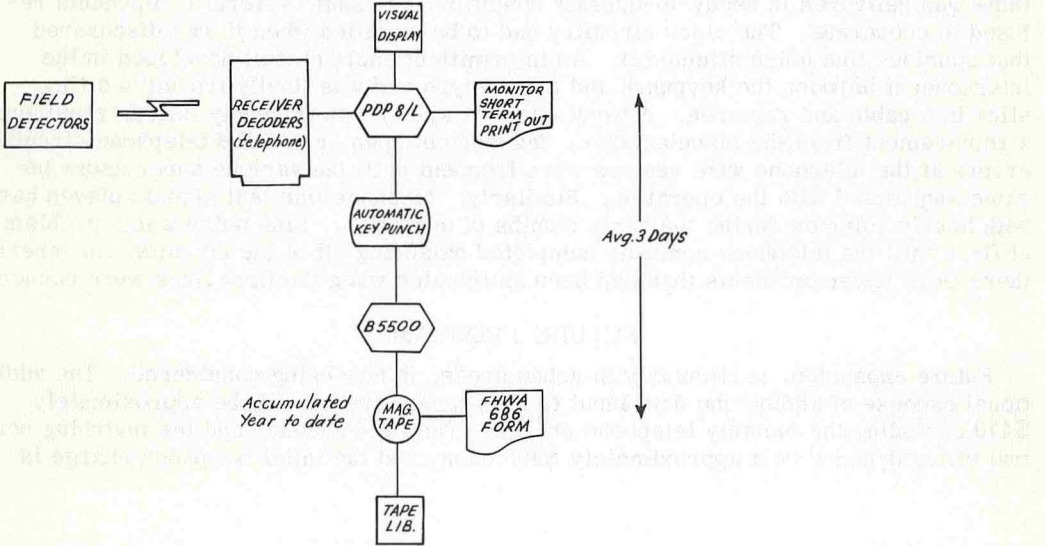
Table 3. Monthly adjustment percentages.

Month	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7
January	91	84	77	73	67	42	59
February	94	87	84	78	71	46	68
March	99	93	93	88	83	51	76
April	102	101	98	96	93	64	90
May	103	106	105	108	106	89	108
June	105	107	108	112	122	125	110
July	105	108	112	122	141	242	130
August	104	107	114	123	142	220	133
September	102	106	108	110	114	115	112
October	103	105	107	106	101	90	116
November	97	99	100	98	89	63	104
December	95	93	90	86	75	58	85

Table 4. Basic station values.

ATR Station	Route	Location	Basic Value	ATR Station	Route	Location	Basic Value
0010	US-20	West Springfield	4,900	3031	I-76	Squirrel Hill	16,600
0020	Penn-77	New Richmond	1,150	3032	I-76	Squirrel Hill	16,500
0030	Penn-255	Penfield	3,600	3033	I-76	Squirrel Hill	17,200
0040	US-6	Wellsboro	2,300	3034	I-76	Squirrel Hill	17,100
0050	LR-08077	Towanda	600	3035	I-76	Squirrel Hill	2,600
0080	Penn-73	Whitemarsh	11,000	3048	US-15	Williamsport	12,600
0150	US-522	McConnellsburg	3,700	3049	US-15	Williamsport	12,600
0160	US-30	Wolfsburg	3,100	3060	Penn-507	Hawley	2,250
0170	Penn-403	Tire Hill	6,000	3081	I-76	Schuylkill Expressway	20,300
0180	Penn-38	Butler	4,750	3082	I-76	Schuylkill Expressway	18,900
0190	Penn-88	Finleyville	4,850	3083	I-76	Schuylkill Expressway	26,800
0200	Penn-65	New Castle	6,200	3084	I-76	Schuylkill Expressway	27,100
0240	US-22 and US-119	New Alexandria	12,700	3085	I-76	Schuylkill Expressway	24,500
0250	US-224	Parkstown	7,700	3086	I-76	Schuylkill Expressway	21,300
0270	Penn-68	Russell City	1,750	3098	I-79	Fort Pitt Tunnel	35,200
0290	Penn-267	Auburn Ctr	850	3099	I-79	Fort Pitt Tunnel	35,100
0350	US-422	Myerstown	9,500	3101	Penn-291	Penrose Avenue	15,600
0360	US-322	Brickerville	3,350	3102	Penn-291	Penrose Avenue	17,400
0390	US-611	Easton	3,650	3103	Penn-291	Penrose Avenue	17,000
0400	US-209	Tamaqua	2,500	3104	Penn-291	Penrose Avenue	15,600
0460	US-11	Berwick	10,400	3178	I-78	Allentown	22,900
0470	Penn-307	Scranton	5,250	3179	I-78	Allentown	22,000
0480	US-11	New Milford	2,550	3220	US-30	Leaman Place	13,300
0498	Penn-309	Coopersburg	9,300	3230	US-220	Centerville	1,850
0499	Penn-309	Coopersburg	9,300	3260	US-322	Clarion	6,100
0510	Penn-44	Coudersport	2,000	3280	US-220	Milesburg	4,850
0520	US-119	Indiana	5,150	3300	Penn-532	Newtown	2,750
0530	US-19	Mercer	6,050	3328	US-11	Hogestown	10,750
0560	US-11 and US-15	Liverpool	10,600	3329	US-11	Hogestown	10,750
2028	US-22	Paxtonia	5,800	3340	US-30	Thomasville	11,000
2029	US-22	Paxtonia	5,550	3508	US-15	Hepburnville	6,350
2038	Penn-65	Leetsdale	9,350	3509	US-15	Hepburnville	6,350
2039	Penn-65	Leetsdale	9,250	3600	US-219 and US-322	Luthburg	2,350
2058	I-83	North York	9,600	3610	Penn-63	Harleysville	5,550
2059	I-83	North York	10,200	3620	Penn-24	Red Lion	2,450
2061		Taylor Bridge (Harrisburg)	9,750	3630	US-219	Bradford	2,800
2062		Taylor Bridge (Harrisburg)	10,100	3640	Penn-307	Clarks Summit	3,350
2063		Taylor Bridge (Harrisburg)	7,450	3650	Penn-26	Marklesburg	1,700
2064		Taylor Bridge (Harrisburg)	7,350	3660	Penn-18	Mechanicsburg	2,450
2078	I-90	West Springfield	5,400	3670	Penn-45	Mifflinburg	4,150
2079	I-90	West Springfield	5,300	3708	I-70	Belle Vernon	13,050
2088	I-76	Monroeville	21,250	3709	I-70	Belle Vernon	13,050
2089	I-76	Monroeville	20,850	3718	I-70	Crystal Springs	4,500
2101	I-83	John Harris Bridge	16,900	3719	I-70	Crystal Springs	4,500
2102	I-83	John Harris Bridge	15,600	3728	I-80	Milton	2,450
2103	I-83	John Harris Bridge	9,200	3729	I-80	Milton	2,450
2104	I-83	John Harris Bridge	10,900	3738	I-81	Chambersburg	4,750
2138	US-1	Kennett Square	5,600	3739	I-81	Chambersburg	4,750
2139	US-1	Kennett Square	5,700	3748	I-79	Portersville	4,750
2168	I-81	Hallstead	4,800	3749	I-79	Portersville	4,750
2169	I-81	Hallstead	4,800	3758	US-22 and US-30	Imperial	5,500
3018	Penn-5	Erie	7,450	3759	US-22 and US-30	Imperial	5,500
3019	Penn-5	Erie	8,200				

Figure 9. Telecount automatic ATR data processing.



Totaling is extremely flexible, and practically any variation can be selected for readout. For any specified time increment, the raw count passing a detector can be supplied. Totals for each detector station or groups of stations during specified time periods are available.

A most important advantage to this very flexible kind of counting is that it provides up-to-date real-time statistics. Annual average daily traffic, calculated by taking a theoretical count and dividing it by 365, provides a predicted traffic curve. With instantaneous processing of counts, the predicted curve can be compared immediately against actual vehicle counts.

The automatic data processing procedure is shown in Figure 9 and can be compared to the manual processing work flow shown in Figure 2.

EXPENDITURES

Expenditures for this system are as follows:

<u>Item</u>	<u>Dollars</u>
Initial expenditure	163,000
Field equipment at collection and remote stations	42,000
Central office equipment	121,000
Nonrecurring telephone charge	868
Monthly telephone charge	2,700
Underground conduit in department right-of-way	4,300

Although the annual operating costs of the telecount system are about the same as the original manual weekly servicing procedure, the central data collecting system has eliminated the manual computations and their inherent human errors, the field recorder problems, and the man-hours consumed in estimating lost hours. It not only greatly reduces the time required to produce the monthly reports but also provides the previously impossible capability of monitoring the operation of all of the field stations simultaneously and collecting real-time short-term counts.

The field equipment was installed by department technicians during the weekly inspection trips around the network under the direction of Automatic Signal Company's staff engineers. This in-house capability eliminated an initial installation charge of \$10,000 that would ordinarily have been added to the cost of the system. The manufacturer's staff and service personnel cooperated fully with the department in starting up the equipment, making service adjustments, and solving prototype problems.

Prototype systems often experience intriguing start-up problems. Ninety percent of the preliminary operations were routine; only the remaining 10 percent provided the intrigue. Although the main engineering design and manufacture were sound and everything was delivered in ready-to-operate condition, as usual, several components refused to cooperate. The clock circuitry had to be modified when it was discovered that spurious line noise affected it. An intermittent short circuit developed in the interconnect between the keypunch and the teletype and was finally traced to a tiny slice in a cable and repaired. A week was lost when a power supply failed, requiring a replacement from the manufacturer. Inadvertent open or shunted telephone circuitry errors at the telephone wire centers were frequent until the various supervisors became acquainted with the operation. Similarly, telephone line test signals played havoc with hourly volumes during the early months of operation. Line noise was a problem at first until the telephone company completed balancing all of the circuits. In general, there were fewer problems than had been anticipated when the first lines were connected.

FUTURE PROGRAMS

Future expansion, particularly in urban areas, is now being considered. The additional expense of adding one data input to the present system will be approximately \$410 excluding the monthly telephone charge. The field encoder and the matching central office decoder cost approximately \$200 each, and the initial telephone charge is

\$10. The monthly telephone charge is computed by the number of air-miles to the nearest collector or trunk-line terminal.

Consideration is also being given to the use of short-interval telemetry reporting for special purpose data collection activities connected with urban transportation studies. This would involve portable automatic traffic detectors or manually initiated traffic data reporting directly into the central office assembly. Programs for developing the software requirements to report vehicle speed, classification, and axle configuration through the present system are currently under way.

CONCLUSION

Other agencies controlling their own complete computer systems could afford to consider dial-up applications. The on-line approach is more adaptable for multiservice applications for future expansion and eventual communication link cost sharing of continuous service activities, particularly considering activities requiring real-time monitoring. Many new monitoring programs, such as large-scale air pollution, stream level, and noise level reports, will be linked to central computing storage and switching installations over the rapidly emerging public and private wire service networks. These new networks will eventually link every home and building equipped with telephone or electric service and provide every type of communications from consumer purchasing and marketing to closed-circuit duplex television programming.

The on-line, real-time approach is the most appropriate for future expansion and will also contribute significantly to highway planning and the transportation effort in general. Even without utilizing the full capabilities of the present communication networks, this approach provides current data for immediate input to planning projects before the information becomes obsolete. Current traffic information provides an invaluable assist to the traffic engineers working with real-time problems. The automated real-time approach also increases the efficiency of the overall system by providing constant surveillance of the entire system to report malfunctions immediately. This automatic monitoring not only increases the system's efficiency but also relieves technical personnel of the tedious manual computations in manipulating large volumes of data and frees them for more productive assignments.

GLOSSARY

accumulator. Combines counts from several detectors into 1 counter without loss in accuracy due to coincidence of simultaneous pulses.

ATR. Automatic traffic recording.

class A line. Voice-grade telephone service.

class C line. Teletype-grade telephone service that has slow speed and usually costs 20 percent less than class A.

decoder. Interface between telephone terminal and computer.

encoder. Interface between vehicle detector and telephone terminal.

Hz. Hertz, the frequency or number of cycles in 1 second of an alternating current.

M-housing. Radar loop detector cabinet.

Ma. Milliampere, 0.001 ampere.

msec. Millisecond, 0.001 sec.

multiplex. Simultaneous transmission of several signals at different frequencies over a single circuit

PE-housing. Photoelectric roadside cabinet.

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PROCEDURE FOR ESTIMATING NATIONAL MARKET AND TOTAL SOCIOECONOMIC IMPACTS OF NEW SYSTEMS OF URBAN TRANSPORTATION

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This paper presents a general procedure for determining the potential national market and total socioeconomic and environmental impacts for an urban transportation system concept that can be considered for implementation in a large number of urban areas. The procedure involves the following closely interrelated steps: (a) statistical classification of all metropolitan areas into relatively homogeneous groups on the basis of their transportation requirements; (b) selection of the most representative area in each group; (c) performance of analytical case studies in each representative area in order to synthesize the optimal system design for that area and evaluate the impacts on user and nonuser population stratifications; (d) statistical analyses of the differences among areas within the same group; (e) performance of sensitivity analyses of each case study guided by these difference analyses; (f) extensions of the results of the case studies to the other areas in each group through the use of the sensitivity and difference analyses; and (g) aggregation of the market estimates for all metropolitan areas and of the total impacts for the country as a whole by user and nonuser population stratifications. Specific methods are given for many of the steps in the procedure, and guidelines are presented for some of the more traditional planning tasks such as case study analyses.

•IN THE study of new systems of public transportation, it is important to be able to estimate the potential range of application of the new system and the consequences of its implementation. These consequences include benefits to system users and other social, economic, and environmental impacts. When private funds are employed in system research and product development, the primary concern is with the size of the market for reasons directly related to the objective of maximizing return on investments, and the various system benefits and disbenefits serve as secondary objectives and as constraints. When public funds are so employed, the proper concern is with the magnitude and distribution of benefits and disbenefits. However, the market aspects must also be considered if the hope is to attract private investment capital into new system research and development.

The problem of estimating the total market and the total social-economic-environmental impacts for new urban transportation systems, even within the single country of the United States, is difficult because of the diverse transportation requirements and environments that characterize the hundreds of metropolitan areas throughout the country. It is not feasible to conduct a detailed design, analysis, and evaluation of a new system concept in every metropolitan area. Rather, it is desirable that a procedure exist whereby the total market and nationwide impact of a new system may be estimated based on limited case studies in some minimum number of selected metropolitan areas.

This paper outlines such a general procedure for determining the total market for a transportation system concept that can be considered for implementation in any of a large number of metropolitan areas and the total user and nonuser consequences of such implementation, based on case studies in a limited number of metropolitan areas and given a body of statistical data on all metropolitan areas. It is based on a method for the classification of metropolitan areas into homogeneous groups and the identification of the most representative areas within such groups and on methods for the design and conduct of case studies within representative areas and the extension of case study results to other metropolitan areas.

It is intended that the primary contribution of this paper should be relative to the overall tasks of planning case studies, selecting case study locales, and extrapolating results to other metropolitan areas, rather than to the more specific core tasks of design, analysis, and evaluation of a single system in a single metropolitan area. However, to ensure that the results of individual case studies are applicable to other metropolitan areas, it is desirable that a certain approach be taken to such design, analysis, and evaluation. Such an approach is therefore outlined.

SUMMARY

A generalized description of the procedure is as follows:

1. Stratify and cluster the total set of metropolitan areas into a number of distinct, relatively homogeneous groups on the basis of their transportation requirements;
2. Identify the most representative metropolitan areas in each group;
3. Perform an analytical case study of the new urban transportation system in each representative metropolitan area in which the optimum form of the new system and its likely social, economic, and environmental impacts on various user and non-user population stratifications (including the probability of its implementation during a specified time period) are determined;
4. Analyze the similarities and differences among the metropolitan areas constituting each group;
5. Utilize intragroup variances such as a guide to the performance of sensitivity analyses of the design and impacts of the new urban transportation system as a function of metropolitan area characteristics;
6. Extend the results of the individual case studies in the several representative areas to the remaining metropolitan areas, group by group, making use of the intragroup variance and the sensitivity analyses results; and
7. Aggregate the estimates for all metropolitan areas to determine the probable total market for the system (and for the subsystems and components of the system) and the probable total social, economic, and environmental impacts of system implementation for the country as a whole by user and nonuser population stratifications.

Although this general procedure is conceptually simple, its accomplishment is not a trivial matter. Each of the steps in the procedure must be performed in a manner consistent with the requirements of the remainder of the procedure. Thus, for example, the extension of case study results in a few areas to the remaining metropolitan areas forces one to be fairly rigorous about the concept of representativeness and thus about the factors entering into the stratification and clustering of metropolitan areas. Moreover, it requires one to plan the conduct of case studies and sensitivity analyses so that the data product is of a form that permits extrapolation to additional metropolitan areas.

DISCUSSION

Underlying Rationale

One of the cardinal assumptions in urban transportation planning is that one can relate transportation requirements to certain measurable characteristics of metropolitan areas, such as land use patterns and intensities and existing travel behavior.

If the vector C_i represents the set of n such characteristics ($C_{i,1}, C_{i,2}, \dots, C_{i,n}$) for metropolitan area i , and R_i denotes the set of p transportation requirements for area i , then

$$R_i = R(C_i) \quad (1)$$

It is further assumed that the optimal system design configuration for that urban transportation system in a particular area is a function of the transportation requirements for the area and the base-line system specification.

$$S_i = S(R_i, S_o) \quad (2)$$

where S_i denotes the set of q system components constituting the optimal system design configuration for metropolitan area i , and S_o denotes the base-line system specification for the q components. Thus, the optimal design can be related to the metropolitan area characteristics, or

$$S_i = S'(C_i, S_o) \quad (3)$$

Through the optimal design of generic system S_o for all m metropolitan areas in the United States, the total national market for the x th system component can be specified as

$$S_{r,x} = \sum_{i=1}^m S_{i,x} \quad (4)$$

where it is understood that $S_{i,x}$ might be 0 for some x components and some i areas.

Similarly, the total of the y th set of impacts, $U_{r,y}$, attributable to the implementation of the urban transportation system in the m metropolitan areas can be specified as

$$U_{r,y} = \sum_{i=1}^m U_{i,y} \quad (5)$$

where U_i is the set of r impacts ($U_{i,1}, U_{i,2}, \dots, U_{i,y}, \dots, U_{i,r}$) in metropolitan area i .

However, the detailed optimal design task for each metropolitan area is a time- and resource-consuming process, and it is not feasible to perform such a task in each of the hundreds of metropolitan areas in the United States. Rather, it is desirable to conduct a detailed case study design of system S_o in one or more metropolitan areas and then to infer the relations of the optimal designs in the metropolitan areas not studied in detail from these case study designs. The design of S_o in area j (not studied in detail) may be stated as a function of design S_i (studied in detail) as follows:

$$S_j = S_i + \Delta S_{i \rightarrow j} \quad (6)$$

where

$$\Delta S_{i \rightarrow j} = f_{i,j}(C_i, C_j, S_o) \quad (7)$$

Here $f_{i,j}$ represents a function unique to observations i and j .

The problem encountered in extrapolating optimal designs for a large number of metropolitan areas from a small number of detailed studies, as specified in Eqs. 6 and 7, is twofold. First, the detailed C_i data are often not available for all metropolitan areas and, when available, are often not compatible. Second, the $f_{i,j}$ function relating the optimal system design changes between areas i and j is often unique to each i, j pair of metropolitan areas and consequently must be continually reevaluated. The procedure outlined in this paper attacks the problem on both fronts.

Let C^\dagger represent that particular subset of s of the characteristics C_i of metropolitan area i , which is available and compatible for all m metropolitan areas. C^\dagger statistics are what might be labeled as aggregate statistics, such as population demographics and

route-miles of roadway by total functional classifications. It is hypothesized that the $\Delta_{i \rightarrow j} S$ relation between areas i and j can be expressed as a function of the C_i^* and C_j^* subsets of the C_i and C_j spaces, or

$$\Delta_{i \rightarrow j} S = g_{i,j} (C_i^*, C_j^*, S_0) \quad (8)$$

where $g_{i,j}$ is again some function dependent on the i,j pair.

The problem of the multiple g functions is approached by restricting ΔS calculations to homogeneous regions in a new orthogonal (or independent) space derived from the s dimensional C^* space. This is accomplished by first applying the multivariate statistical technique of principal components analysis to the C^* data. The result is the generation of an orthogonal space of t dimensions, denoted by F , in which most of the original C^* information is preserved and where $t \leq s < n$. The $\Delta_{i \rightarrow j} S$ equation can then be written as

$$\Delta_{i \rightarrow j} S = h_{i,j} (F_i, F_j, S_0) \quad (9)$$

Next, the set of all m metropolitan areas is classified into μ homogeneous groups Q_k with respect to the locations of each area in F space. It is hypothesized that the $h_{i,j}$ function relating the v_k areas within the same Q_k group is continuous and differentiable in each of the t dimensions of F . Moreover, it is hypothesized that the t first derivatives of S are constant when the most representative area, i_k , say, in group Q_k , is related to any other area j_k in Q_k . Thus,

$$\Delta_{i_k \rightarrow j_k} S = (\partial S / \partial F_{i_k}) \cdot \Delta_{i_k \rightarrow j_k} F \quad (10)$$

In other words, since the new characteristics defining metropolitan areas i_k and j_k , F_{i_k} , and F_{j_k} are independent and since areas i_k and j_k are relatively close in space F (that is, relatively similar in terms of their urban characteristics C^* and thus presumably similar in terms of transportation requirements R), the optimal design of system S_0 in area j_k , S_{j_k} can be approximated from the optimal design in area i_k , S_{i_k} through a set of linear relations between S and F .

The total market $S_{T,x}$ for any subsystem or component x of system S_0 may be estimated by extrapolating case results to similar metropolitan areas in the manner outlined above and by summing over all areas.

$$S_{T,x} = \sum_{k=1}^{\mu} \sum_{j_k=1}^{v_k} S_{j_k,x} \quad (11)$$

Similarly, the total impact U of social, economic or environmental condition (or all of these) on a particular type y or on a particular actor set y , that would result from the full implementation S_T of system S_0 , may be estimated by extrapolation of the corresponding results from the case studies to other areas within the homogeneous groups and by summation over all groups.

$$U_{T,y} = \sum_{k=1}^{\mu} \sum_{j_k=1}^{v_k} U_{j_k,y} \quad (12)$$

Stratification and Clustering of Areas

The method for classifying metropolitan areas into relatively homogeneous groups with respect to their transportation requirements is based on the staged implementation of complementary multivariate statistical analysis techniques. A detailed discussion of the general classification methodology is given by Golob et al. (13); a methodological summary with specific application to urban transportation problems is contained in this paper.

General references for the various multivariate statistical techniques employed in the stratification and clustering method (and also in the identification of representative

areas and the intragroup variance analysis presented in later sections) are Anderson (2), Kendall (19), Morrison (22), and Cooley and Lohnes (12). References for specific applications of the techniques are given in the following discussions.

In the first stage of the classification method, those C_i characteristics of metropolitan areas that are related to the R_i transportation requirements for the areas are selected from the set of all available metropolitan area statistics, yielding the subset C_i^* . This selection process is conducted by transportation planners (preferably a multidisciplinary team) and is accomplished with regard to the scale aspect of the base-line system S_0 under study (e.g., arterial transportation requirements as opposed to major activity center distribution requirements).

Simple and canonical correlation analyses are conducted on the selected variables in the second stage of the method. In the simple correlation phase, the existence of a high degree of association between 2 variables is identified in order to eliminate extreme multicollinearity in the data and in order to eliminate variables with a large number of missing data observations. In the canonical correlation phase, the effects of variables judged as being marginally important in the data structure are explicitly identified. Linear combinations (components) of 1 variable subset are correlated with linear combinations of a second subset, where the second subset is made up of the first subset plus the marginal variables in question. The components for each subset are linearly independent of each other (orthogonal) and are chosen such that the correlation (called canonical correlation) between the components of the first subset and the corresponding components of the second subset are maximized. If each component of the first subset is significantly correlated with only 1 component of the second subset, and conversely, then the 2 component spaces are assumed to be essentially identical, and the marginal variables are assumed to have no significant effect on the data structure. The process is repeated for the various marginal variables. Correlation significance in both phases is determined through the use of statistical distribution tests applied to product-moment correlation coefficients.

The remaining variables are then factor analyzed by using a principal-components approach in the next stage of the classification procedure. Specific expositions on this multivariate technique are given by Harmon (16) and Hotelling (17); and Green and Tull (14) and Harder (15) discuss market research applications. The principal components analysis is used to reduce the dimensionality of the data in a manner such that a minimum of information is lost; describe the new orthogonal dimensions F (called factors or components) as linear combinations of the original variable dimensions; and estimate the measurements (often called factor scores) of the metropolitan areas on these orthogonal factors. The interpretation of the factors in terms of the original variables permits a description of the basic or underlying "dimensions" characterizing the metropolitan areas and is in itself useful in analyzing the similarities and differences among metropolitan areas with respect to their transportation requirements. Examples of (nontransportation specific) studies of metropolitan areas based on factor analyses can be found in Isard (18), Berry (3, 4, 5), Moser and Scott (23), and King (20).

The output of the stratification and clustering method—the classification of metropolitan areas into μ relatively homogeneous groups Q_k , where $k = 1$ to μ —is produced in the final cluster analysis stage of the method. The distribution of metropolitan areas in the orthogonal factor space, given by the F_i factor scores, served as the basis for the cluster analysis. The specific cluster analysis technique used is described by Rubin and Friedman (24) and involves a hill-climbing algorithmic search for the optimal partition of a data set, optimality being measured with respect to a selected criterion. The criterion chosen is the so-called Wilkes-Lambda criterion, defined as the logarithm of the ratio of the determinant of the total data scatter matrix to the determinant of the pooled data scatter within the individual groups. Heuristically defined data reassignments and program restarts from random initial partitions are employed in order to test for local maxima.

The cluster analysis stage of the method is reinitiated for each grouping of areas into a specified different number of groups. A plot of the monotonically increasing Wilkes-Lambda criterion function versus the number of groups for a particular appli-

cation is used to identify the critical number of groups (if one exists) that best describes the natural clustering in the data. (The criterion rate of increase per cluster will decline after such a critical number is passed, as opposed to the rate of increase in the criterion function immediately prior to this critical number.) Of course, in any particular application of the method, the number of groups might be a specified constant if a given number of case studies are to be performed.

A number of previous studies have grouped spatial areas by using various techniques of numerical taxonomy. These techniques have been in general less flexible than the technique presented here, have not been staged within a comprehensive classification procedure, and have not been performed with respect to urban transportation requirements; the studies are those reported by Berry (5, 6, 7), King (20), and Stone (25). Similar studies specific to urban transportation are reported by Bottiny and Goley (8) and Zenk and Frost (26).

Identification of Representative Areas

The method for identifying the most representative areas within each homogeneous group Q_k is based on the application of 2 multivariate statistical techniques using inputs from the stratification and clustering process. A detailed discussion of the methodology underlying this method is given by Golob et al. (13), and references for the methodologies of the specific statistical techniques employed are given in the previous section.

The first technique used is a correlation analysis of areas. For each separate group of metropolitan areas, a correlation matrix containing the product-moment correlation coefficients between each area in the group and each of the other areas in the group on the basis of the measurements of these areas on the final set of C^\dagger variables is generated. A count of the number of significant correlations for each area then gives an indication of the overall degree of association between the area and each of the remaining areas in its group, and the rank order of the areas in each group on the basis of this count is 1 input to the identification of representative areas. This analysis process is similar to that reported by Zenk and Frost (26).

The second technique is that of discriminant analysis. In this technique linear functions of the F_i factors that best differentiate the known groups of areas are calculated. These functions are then used to reclassify the areas into groups, and the areas that prove difficult to reclassify into their original groups are identified. Subsamples of areas are used in multiple calculation of the discriminant functions in order to compensate for the bias in discriminant classification.

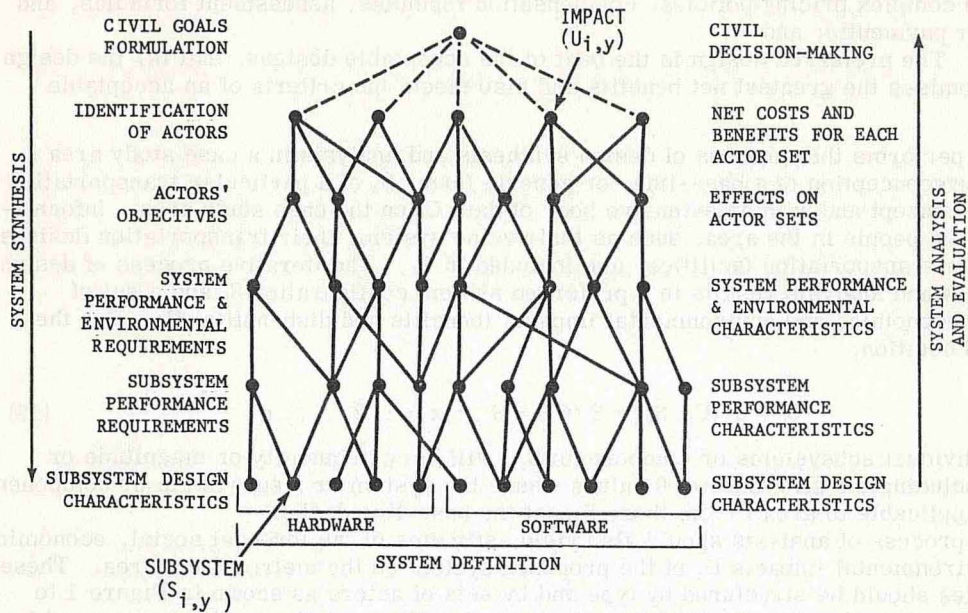
The identification of the most representative areas then involves the compilation of the results from the correlation analysis and discriminant analysis with an additional output from the cluster analysis stage of the stratification and clustering method: the matrix of generalized distances from each object to the center of each group. From these 3 inputs a rank ordering of areas in each group can be generated, partially through the subjective judgments of statistically trained analysts. The most representative areas then constitute the set of case study locales, unless considerations such as microdata availability and local planning cooperation dictate the use of the next most representative area for a particular group Q_k .

Case Studies: Design Synthesis and Analysis

Recognizing that the needs of several sets of actors are to be considered in the design of major civil systems, one should employ a design process equivalent to that shown conceptually in Figure 1. This iterative process of synthesis and analysis includes identification of the needs of multiple sets of actors, development of a system definition for that optimum design S_i in metropolitan area i , and an evaluation of the net costs and benefits U_y to each actor set y . [For discussion of this model concept and illustrative examples, see Canty (10), Alexander (1), and Liberakis (21).]

The design process shown in Figure 1 can be described as including the following activities:

Figure 1. Design process for civil systems.



1. Identification is made of the actors who would be served by or otherwise affected by the proposed new system, or would be influential in determining whether the system is to be implemented;
2. Objectives are defined for each actor set, relative to system effects;
3. The relative importance of each objective and system effect is determined for each actor set;
4. Relevance is established among subsystem design characteristics (both hardware and software), subsystem and system performance and environmental characteristics, and system effects;
5. Through the process of system synthesis, system performance and environmental requirements are translated into subsystem performance requirements and thence into subsystem design;
6. For each of a number of system configurations, through the process of system analysis, system performance and environmental characteristics are estimated;
7. System performance and environmental characteristics are evaluated in terms of their effects on the various actor sets;
8. The relative importance of each of the system effects to each actor set are considered in the evaluation of the net benefits or disbenefits to each;
9. A range of system design characteristics, both hardware and software, is considered so that one may accomplish a sensitivity analysis, tracing the impact, positive or negative, of design variations on the benefits or disbenefits to each actor set;
10. Depending on the degree of precision to which the process given above can be accomplished for any actor set, one may estimate the degree to which that system design is desirable, tolerable, or unacceptable to a particular actor set, and thus whether those actors can be expected to support, to be indifferent to, or to oppose implementation of the proposed system;
11. By variation of the system design, including both hardware and software subsystem characteristics, one may search for a preferred design—however, it is not likely that this preferred design will be optimal in the simplistic sense of maximizing total net benefits summed over all actors because the distribution of costs and benefits is also important;
12. An acceptable design is defined as one for which no net disbenefits (negative impacts exceeding positive benefits) are forecast for any actor set (preferably net

benefits are distributed among all actors in some relatively equitable manner that may require complex pricing policies, compensation formulas, assessment formulas, and transfer payments); and

13. The preferred design is the best of the acceptable designs, that is, the design that promises the greatest net benefits and also meets the criteria of an acceptable design.

One performs this process of design synthesis and analysis in a case study area i with a preconception of a base-line, or generic form, S_0 of a particular transportation system concept and with an extensive body of data C_i on the case study area. Information on the people in the area, such as their value system, their transportation desires, and other transportation facilities, are included in C_i . The iterative process of design synthesis and analysis results in a preferred system configuration S_i and a set of social, economic, and environmental impacts (benefits and disbenefits) U_i . Per the adopted notation,

$$S_i = S'(C_i, S_0) = S^0(C_i) = S_{i,x}; x = 1, 2, \dots, q \quad (13)$$

The individual subsystems or components $S_{i,x}$ will vary in quantity or magnitude or both (including the allowance of 0 values where the system or a subsystem or component is not applicable to area i from those $S_{0,x}$ of the base-line design).

The process of analysis should also yield estimates of the forecast social, economic, and environmental impacts U_i of the proposed system on the metropolitan area. These estimates should be structured by type and by sets of actors as shown in Figure 1 to permit an analysis of the distribution of system benefits and disbenefits by type and by sets of actors (i.e., social, economic, ethnic, or civic groupings). Thus,

$$U_i = U_{i,y}; y = 1, 2, \dots, r \quad (14)$$

where $U_{i,y}$ is the net impact on actor set y in metropolitan area i . Also, note that $U_{i,y}$ is dependent on the characteristics C_i of metropolitan area i inasmuch as $U_{i,y}$ is a function of S_i , which in turn is a function of C_i , and inasmuch as the relative importance of the various social, economic, and environmental effects of S_i to an actor set y are dependent on the physical environment of area i , the affluence of actor group y in area i , and other factors included in the set of characteristics C_i .

It is desirable that the analysis include the development of probability statements relative to the likelihood of implementation of the preferred system and the impacts thereof in the case study areas in the planned time era. Let P_i denote the probability of implementation of the preferred system S_i in metropolitan area i . Also let $P_{i,x}$ and $P_{i,y}$ respectively denote the probability of implementation of the x th subsystem of S_i and the probability of occurrence of the y th impact, where these probabilities are not necessarily equal to P_i .

It is desirable also that the estimates of impact include a distribution overtime. It should be clear that the consideration of such probabilities and the estimation of such distributions are important elements in the system design and analysis process.

Intragroup Variance Analysis

A statistical analysis of the similarities and differences between metropolitan areas within the same homogeneous group Q_k is conducted in this step of the procedure. The primary multivariate statistical technique utilized is principal-components factor analysis, the methodology of which is discussed (and referenced) in a previous section. The objectives of the factor analysis are also similar to those specified in the earlier section except that the set of observations is the v_k metropolitan areas that are classified as members of group Q_k , and the process is repeated for each of the μ groups. These objectives are to reduce the dimensionality of the C^* data in a manner such that a minimum of information is lost and to describe the new orthogonal factor dimensions as linear combinations of the original s variables constituting the C^* space.

The factor spaces resulting from these analyses of the s C^* variables are denoted by F_k^* ($f_{1,k}^*, f_{2,k}^*, \dots, f_{w,k}^*$) for group Q_k ($w \leq s$). These factors constituting the F^* space

may or may not be similar to the factors constituting the F space resulting from the factor analysis of the total metropolitan area population, depending on whether the areas exhibit similar or different distributions in C^* space when separated into groups or when pooled in 1 group. The independence of the factors in F_k^* space is important in the performance of the sensitivity analysis step of the procedure discussed in the next section, and, together with the reduction in dimensionality, aids in the interpretation of the differences among the areas classified as being homogeneous (relative to the areas in other groups).

Case Studies: Sensitivity Analyses

The case study process outlined in this paper includes 3 types of sensitivity analyses. The first of these, referred to in a preceding section, is employed in order to develop an "optimal" or preferred design and may be viewed as involving quantities of the form $\partial U_{i,y}/\partial S_{i,x}$ with C_i assumed to be constant.

The remaining sensitivity analyses have the purpose of developing estimates of the quantities $\partial S_{i_k,x}/\partial F_{i_k}^*$ and $\partial U_{i_k,y}/\partial F_{i_k}^*$ for use in the extrapolation of case study results S_{i_k} and U_{i_k} from area i_k in homogeneous set k of metropolitan areas to other areas j_k in k . (For simplicity, the subsubscript k will be omitted in the remainder of this section. However, it will be understood that the sensitivity analysis procedure outlined is repeated for each case study area, that is, for each of the μ values of k , assuming that there is 1 case study per homogeneous group.)

The quantities $\partial S_{i,x}/\partial F_i^*$ and $\partial U_{i,y}/\partial F_i^*$ are developed through a structured set of sensitivity analyses of the preferred system design and its impacts in metropolitan area i , where variations in the set of characteristics C_i^* are hypothesized. The analysis of intragroup variance outlined in the preceding section is utilized in structuring the sensitivity analyses. The relative loadings of the variables entering into C^* on the factors constituting the space F^* provide an indication of which of these elements of C_i^* should be varied as part of the sensitivity analysis, as well as a measure of their contribution to variations in F_i^* .

Thus, those elements of C^* that are primarily responsible for the constitution of the factors in F^* are among the variables chosen. Let $\Delta C_{i,z}^*$ denote some variation in the z th element of C_i^* such that

$$C_{i,z}^{*'} = C_{i,z}^* + \Delta C_{i,z}^*$$

$$C_i^{*'} = C_{i,1}^*, C_{i,2}^*, \dots, (C_{i,z}^* + \Delta C_{i,z}^*), \dots, C_{i,s}^* \quad (15)$$

Corresponding changes are made in the larger body of C_i data to yield a new data set C_i' (for example, through a hypothetical change in land use density or per capita income values). The design process is iterated for C_i' , yielding a new preferred system design S_i' and a new set U_i' of forecast impacts, such that

$$\Delta S_{i,x} = S_{i,x}' - S_{i,x} \quad (16)$$

$$\Delta U_{i,y} = U_{i,y}' - U_{i,y}$$

The change $C_{i,z}^{*'}$ is also mapped into space F^* by calculation of the changes in the factors of F^* in proportion to the loading of element $C_{i,z}^*$ on those factors, producing a net change F^* such that $C_{i,z}^{*'}$ is mapped onto $F_{i,z}^{*'}$, where

$$F_i' = F_i^* + \Delta F^* \quad (17)$$

This process is repeated for additional elements $C_{i,w}^*$, resulting in alternative variations ΔF^* and alternative changes $\Delta S_{i,x}$ and $\Delta U_{i,y}$. The additional elements should be chosen in such combination as to sequentially produce variations in the w dimensions of ΔF^* or at least to ensure against multicollinearity in the variations in ΔF^* . From the set of approximately w variations in $C_{i,z}^*$, one may estimate the partial derivatives.

$$\partial S_{i,x}/\partial F_i^* \approx \Delta S_{i,x}/\Delta F_i^* = (S_{i,x}' - S_{i,x})/(F_{i,z}^{*'} - F_i^*) \quad (18)$$

$$\partial U_{i,y}/\partial F_i^* \approx \Delta U_{i,y}/\Delta F_i^* = (U'_{i,x} - U_{i,y})/(F_i^{*'} - F_i^*) \quad (19)$$

Estimation of Total Market and National Impact

The total market for system S_0 over m metropolitan areas is estimated by extrapolating the results of individual case studies in several metropolitan areas, which are each representative of a relatively homogeneous group of metropolitan areas, to the other metropolitan areas that constitute each such group, and by summing over the several groups. A similar process is involved in estimating the total national impact of such system implementation. It will be desirable to stratify the market for system S_0 by subsystems and components and to stratify the national impact by social, economic, and environmental impacts on various sets of actors.

Let i_k be a representative metropolitan area in a homogeneous group k containing v_k members, and let a set of system design and analysis and sensitivity analysis exercises be accomplished for system concept S_0 in area i . Let j be any of the $(v_k - 1)$ other members of group k . Because the points $C_{i_k}^*$ and $C_{j_k}^*$ are known in C^* space and the corresponding points $F_{i_k}^*$ and $F_{j_k}^*$ in F^* space, one may approximate the preferred value of system design S_{j_k} and system impacts U_{j_k} thusly:

$$S_{j_k} = S_{j_k,x}; \quad x = 1, 2, \dots, q \quad (20)$$

$$S_{j_k,x} = S_{i_k,x} + (\partial S_{i_k,x}/\partial F_i^*) \times (F_{j_k}^* - F_{i_k}^*) \quad (21)$$

$$U_{j_k} = U_{j_k,y}; \quad y = 1, 2, \dots, r \quad (22)$$

$$U_{j_k,y} = U_{i_k,y} + (\partial U_{i_k,y}/\partial F_i^*) \times (F_{j_k}^* - F_{i_k}^*) \quad (23)$$

The total market for system S_0 may be expressed as follows:

$$S_T = S_{T,x}; \quad x = 1, 2, \dots, q \quad (24)$$

$$S_{T,x} = \sum_{k=1}^{\mu} \sum_{j_k=1}^{v_k} P_{j_k,x} S_{j_k,x} \quad (25)$$

If separate probability statements are not developed for each j_k by extrapolation from the values for areas i_k , an alternative is to apply the same probability estimates to all members of the homogeneous group k . Thus,

$$S_{T,x} = \sum_{k=1}^{\mu} P_{i_k,x} \sum_{j_k=1}^{v_k} S_{j_k,x} \quad (26)$$

$$S_{T,x} = \sum_{k=1}^{\mu} \left\{ P_{i_k,x} \sum_{j_k=1}^{v_k} \left[S_{i_k,x} + (\partial S_{i_k,x}/\partial F_i^*) \times (F_{j_k}^* - F_{i_k}^*) \right] \right\} \quad (27)$$

Similarly,

$$U_T = U_{T,y}; \quad y = 1, 2, \dots, r \quad (28)$$

$$U_{T,y} = \sum_{k=1}^{\mu} \left\{ P_{i_k,y} \sum_{j_k=1}^{v_k} \left[U_{i_k,y} + (\partial U_{i_k,y}/\partial F_i^*) \times (F_{j_k}^* - F_{i_k}^*) \right] \right\} \quad (29)$$

APPLICATIONS

The procedure described here is being applied by the Transportation Research Department of the General Motors Research Laboratories in a study of a particular arterial transportation system concept—the Metro Guideway. The Metro Guideway concept is described by Canty (11) and consists of integrated facilities for dual-mode automobiles, personal rapid transit and group rapid transit, and automated freight movement. However, the procedure is not restricted in application either to the Metro Guideway system or even other transportation systems at the metropolitan scale. The general procedure should also be useful in the study of other urban systems such as education, housing, and medical care, and the study of transportation systems that have application at other levels of urban structure, e.g., major activity centers, central cities, and townships, as well as at the metropolitan scale. A general consideration of the applicability of various types of transportation systems at various levels of urban structure and scale is given by Canty (9).

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CAPABILITIES OF COMPUTERIZING COMPOSITE MAPPING FOR SIMULATING LOCATION ZONES FOR SELECTED ECONOMIC ACTIVITIES AND PUBLIC SERVICES

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ABRIDGMENT

•A NEW composite mapping system (CMS) has been developed for land use modeling in states and regions and is specially designed for locating "efficiency gradients" or optimal zones for selected industries, major public facilities, and the like. The new process can readily handle a great variety of geographic data, local economic data, and transportation and social service phenomena. It can accept inputs of any form—tabular, printed maps, or sketch maps. Its outputs are cartographic and statistical. It permits any combination of spatial data to be overlaid, with various weights, and readily composed into simulated patterns called "composite maps."

This particular process, developed in the Economic Development Administration (EDA) of the U. S. Department of Commerce, is not the only or best computer program for simply displaying geographic factors. Various other line and symbol printing programs have been developed, some using special equipment. This one requires only a medium memory capacity and a conventional high-speed printer.

The particular capabilities for which CMS was developed are national grid coverage; automatic retrieval, mapping, and display of EDA's vast variety of socioeconomic data; ability to mix any number of desired factors and forms that come up in ordinary practice; and ability to harness statistical packages such as multiple regression for weighting a number of interacting factor maps and explaining "dependent" maps of social or economic change.

Thus, CMS is a kind of "hopper" for mixing all sorts of factor maps into any weighted combination, either with given weights or with weights derived by running dependent factor maps through standard statistical routines.

The present map matrix covers the United States with a grid of approximate 4 square mile cells (more accurately, 2 min of latitude by 2 min of longitude). Any states or desired geographic regions may be selected and implemented with geographic detail. It is not necessary to specify coordinates for introducing new maps or data for census areal units, for their locations and boundaries either are precoded in the map matrix or may be projected onto the blank grid of the county or any sector of it.

EDA's computer mapping laboratory has created map matrices (coded maps) of all counties of the coterminus United States at a scale of 1:500,000 in standard sectors of 240 × 240 miles and cells of 2 × 2 miles (Fig. 1). Each county is identified by a unique 3-character code that constitutes the map dictionary and that makes possible automatic mapping of any data given in tables of counties. Where finer subdivisions are necessary, another map matrix at the same scale has been built for minor civil divisions (MCD); at present, this matrix covers 4 western states having extremely large counties. Since the fourth count data of the 1970 census will have some 125 characteristics by minor civil divisions, this MCD matrix can be developed for any part of the country. The heart of the system must be an adequate map file that may ingest data from original county or other fixed geographic units, may take free form maps, or may create hypothetical patterns.

CMS has been used by EDA for regional and national economic and social data mapping and composite mapping. The Four Corners Commission in the states of Utah, Arizona, New Mexico, and Colorado has used it for searching out optimal locations for 29 categories of industrial growth (1). It is now being used in Utah for industrial location planning. It is being adapted in Colorado for analyzing patterns of social statistics. It is used in Arizona for locating health and other public facilities with respect to social and geographic factors. It is being studied by federal interagency planning groups in the West for handling a vast variety of geographic factor maps. And it is being considered for analyzing patterns of energy-producing and energy-consuming locations in the Rocky Mountain Region. It may be of special interest to coastal states, for the grid pattern extends out over the continental shelf, where it may be used for maritime, fishery, or mineral studies that may need to combine numerous factors of climate, season, oceanography, and geology.

CMS itself does not embody analytic models. The art of using CMS revolves around selecting and weighting factors. Land use modeling requires a knowledge of industries and location theory; socioeconomic index mapping requires a knowledge of social phenomena. The appropriate model for each use depends on this depth perspective and the analyst's style.

Socioeconomic data are usually given by counties, minor civil divisions, and places, here called block maps (Fig. 2). They may be taken in directly from tape or tables by county or any location code. There is an infinite variety of such data around from the censuses—population, agriculture, or industry—and business reporting series of various kinds. EDA's data bank contains more than 6,000 such characteristics for counties alone, and these are automatically convertible to maps.

Many important variables for land use planning may be found in the form of free form maps, such as mineral zones, water supply systems or zones, gas supply systems or zones, rail patterns or accessibility zones, or regional market densities. These differ from the block maps in being conformal, physical, and more precise.

Special qualitative maps may also be introduced, such as regional "business climate factors," tax variation, community attitude variation, positive to negative promotional policies for a given objective, or differences in quality of living. It is apparent that these can be very useful in certain locational studies. The CMS program converts all these forms into grid maps at uniform scale, and this makes it possible to mix the different map forms into composite maps.

The practical applications of CMS are the following.

1. From any tabular or tape input data on population, agriculture, minerals, manufacturing, business, or housing, CMS can record and display quickly, at very low cost, patterns of any socioeconomic statistics over large regions.
2. Socioeconomic condition mapping is possible by a composition of relevant maps. For example, an index map of social conditions at one or several dates may be obtained by superimposing maps of unemployment, labor participation rate, population change, educational achievement, housing defects, or infant mortality (Fig. 3).
3. Mapping of intercensus change may be very useful. Significant changes over time in variables such as value added in production by a certain industry or change in labor occupational categories can be mapped automatically. A very meaningful application, for example, is to show intercensus rate of change in a map of socioeconomic conditions.
4. Efficient locations of an industry or a major public facility can be tested by a composition of a set of factor maps. This sort of simulation requires careful selection and weighting of factors. The purpose and limitations must be determined. The location of a given industry may signify only the within-region optimal location after an economic study has determined the between-regions feasibility of the industry; i.e., the optimal location map reflects only the resources and the distributive networks of this region. For example, in Utah's initial test model, economists first selected certain industries that were feasible within the state's resource-cost characteristics. One of the industries was furniture production, and the main location factors and weights were obtained from technical literature, as follows:

Figure 1. U.S. map matrix used in CMS and example factor map detail.

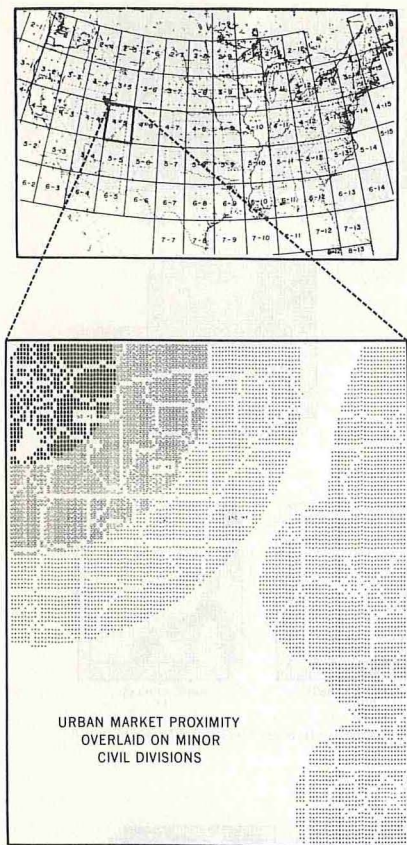


Figure 2. Development of CMS maps.

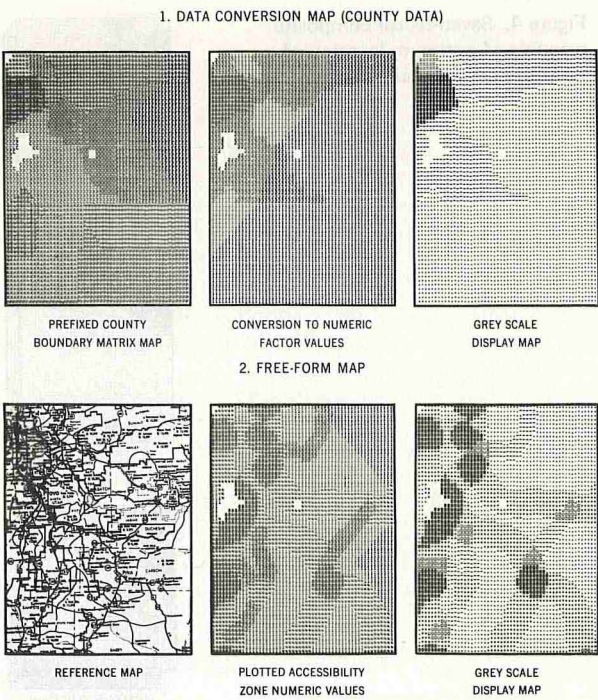


Figure 3. Composite map of social conditions.

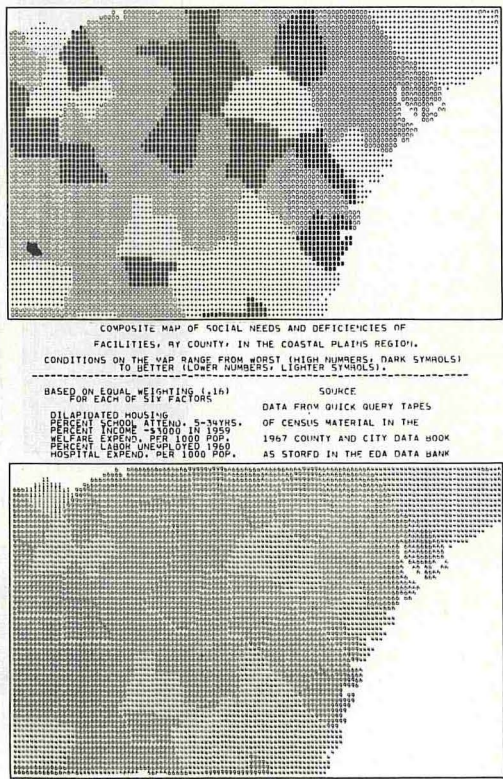
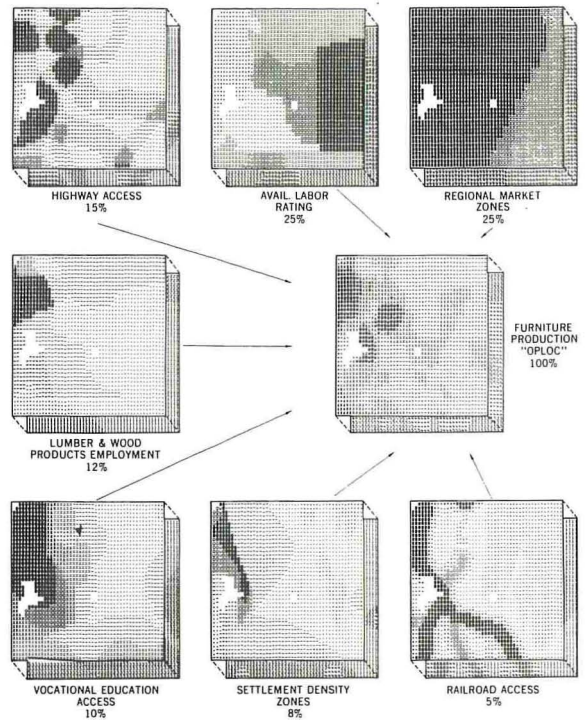
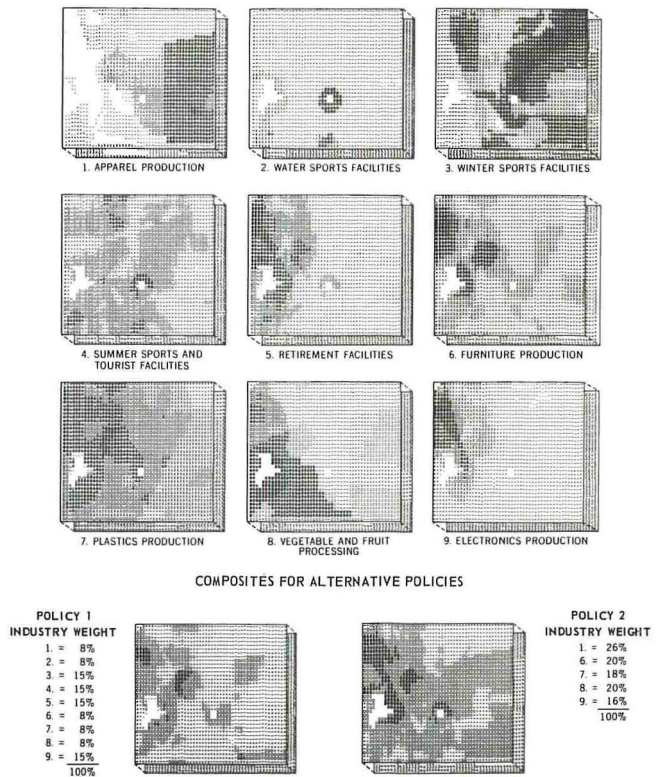


Figure 4. Seven-factor composite mapping of optimum location of furniture production industry.



These examples show only a small portion of Utah, so that digital detail can be seen in this reduction. The necessary area of search must cover a larger field, i.e. state or interstate region.

Figure 5. Composite mapping of favorable multiple-industry locations.



These examples show only a small portion of Utah, so that digital detail can be seen in this reduction. The necessary area of search must cover a larger field, i.e. state or interstate region.

<u>Factor</u>	<u>Weight</u>
Lumber and wood products	0.12
Federal and state highway accessibility	0.15
Railroad accessibility	0.05
Local settlement density	0.08
Regional market zones	0.25
Vocational training accessibility	0.10
Labor availability rating (a special map of 5 conditions)	0.25

The resulting furniture optimal location map is shown in Figure 4. According to the report (2), "Salt Lake City emerges as the most likely spot within the State, but is followed closely by Heber, Provo, and Payson. Slightly less attractive, but still significant, are Brigham City, Logan, Vernal, Nephi, Manti, Green River, Orangeville/Castledale, Richfield, Fillmore, Delta and Kanab."

There are several ways to approach the question, What are the relevant influences and weights?

1. Industrial management judgment may initially indicate the main inputs, relative costs, locational prerequisites, marketing characteristics, and a rough ranking of factors considered important for the industry's location.

2. Relevant literature on specific industries exists in business publications, state bureaus of economic research and federal agencies, studies by EDA, various metropolitan studies, and economic and geographic journals.

3. National or state input-output tables can be interpreted to rank important component costs. They overlook certain geographic variations and business "climate" factors, but these must be sought from sources 1 and 2.

4. Factor weights may be estimated by multiple regression where the reference "universe" is the larger region or another region comparable to the subject region. The target industry map constitutes the dependent variable, and all the locational factor maps constitute the independent variables. All of these maps will run through a multiple regression routine that reads the digital values of all identical cells, map by map.

5. Any number of individual industry optimal location maps may be combined into a multi-industry optimal location map (Fig. 5), which shows relatively strong zones of industrial potential, i.e., "growth areas." This is a common problem in development planning. CMS offers a way to rank industries and their locational propensities and to illustrate "policy" in geographic form. The selected industries may be differently weighted for alternate policies such as quickest labor absorption or lowest capital-job ratio.

6. If the problem requires finer location, it may be worked out by a sequential optimal location process. First, individual industries may be ranked by dominance or independence or both in the desired industrial mix. Then the dominant industries are located first. These locations are taken as given factors for the locations for other industries. A valuable purpose of this is to tailor expensive infrastructure to the most efficient locations and the sequential timing of a time-phased plan. Thus, by trial and feedback, it is possible to approach optimal regional combinations of industry and infrastructure.

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The **National Academy of Engineering** was established on December 5, 1964. On that date the Council of the National Academy of Sciences, under the authority of its act of incorporation, adopted articles of organization bringing the National Academy of Engineering into being, independent and autonomous in its organization and the election of its members, and closely coordinated with the National Academy of Sciences in its advisory activities. The two Academies join in the furtherance of science and engineering and share the responsibility of advising the federal government, upon request, on any subject of science or technology.

The **National Research Council** was organized as an agency of the National Academy of Sciences in 1916, at the request of President Wilson, to provide a broader participation by American scientists and engineers in the work of the Academy in service to science and the nation. Its members, who receive their appointments from the President of the National Academy of Sciences, are drawn from academic, industrial, and government organizations throughout the country. The National Research Council serves both Academies in the discharge of their responsibilities. Supported by private and public contributions, grants, and contracts and by voluntary contributions of time and effort by several thousand of the nation's leading scientists and engineers, the Academies and their Research Council thus work to serve the national interest, to foster the sound development of science and engineering, and to promote their effective application for the benefit of society.

The **Division of Engineering** is one of the eight major divisions into which the National Research Council is organized for the conduct of its work. Its membership includes representatives of the nation's leading technical societies as well as a number of members-at-large. Its Chairman is appointed by the Council of the Academy of Sciences upon nomination by the Council of the Academy of Engineering.

The **Highway Research Board** is an agency of the Division of Engineering. The Board was established November 11, 1920, under the auspices of the National Research Council as a cooperative organization of the highway technologists of America. The purpose of the Board is to advance knowledge of the nature and performance of transportation systems through the stimulation of research and dissemination of information derived therefrom. It is supported in this effort by the state highway departments, the U.S. Department of Transportation, and many other organizations interested in the development of transportation.

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